# Overview of Photocatalysis, Photocatalytic Surface Materials Studies, and *Demonstration of Self-Cleaning Materials for Space and Terrestrial Based Applications at the Infinity Science Center at NASA Stennis Space Center*

Presented by
NASA Stennis Space Center
July 11, 2012

# Stennis Space Center

# John C. Stennis Space Center

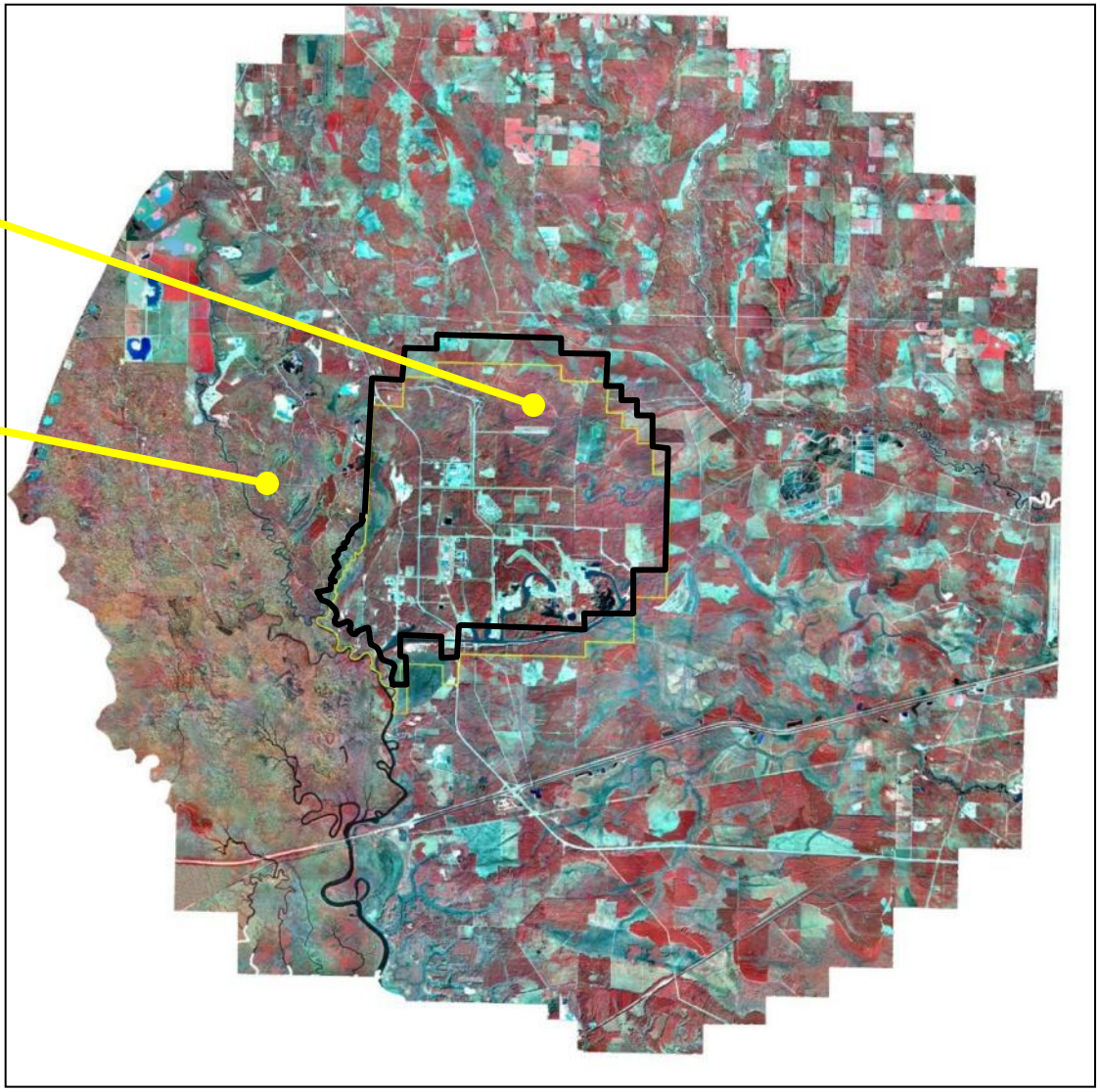
# Stennis Space Center

-13,800 Acre Fee Area

-125,000 Acre Buffer Zone

Nation's largest rocket engine testing facility

- Built in 1963 to support the Apollo space program



# Stennis Space Center (SSC)

A unique Federal City hosting the NASA Shared Services Center and more than 30 federal, state, academic and private organizations, as well as numerous technology-based companies

# Resident Agencies at SSC

*Stennis Space Center*

**Department of Defense**
- Commander, Naval Meteorology & Oceanography Command
- Naval Oceanographic Office
- Naval Research Laboratory
- Naval Small Craft Instruction and Technical Training School
- Navy Special Boat Team 22
- Navy Human Resources Service Center Southeast

**Department of Commerce**
- NOAA, NWS, National Data Buoy Center
- NOAA National Marine Fisheries Service
- NOAA National Coastal Data Development Center

**Environmental Protection Agency**
- Environmental Chemistry Laboratory
- Gulf of Mexico Program

**Department of Interior**
- U.S. Geological Survey, Hydrologic Instrumentation Facility

**Department of Energy**
- Strategic Petroleum Reserve

**State of Mississippi**
- Mississippi Enterprise for Technology
- Enterprise for Innovative Geospatial Solutions

**State of Louisiana**
- Louisiana Technology Transfer Office, Louisiana Business & Technology Center/LSU

**Center for Higher Learning**
- Mississippi State University
- University of Southern Mississippi
- University of Mississippi
- University of New Orleans
- Pearl River Community College

**Mississippi State University**
- Northern Gulf Institute

**University of Southern Mississippi - College of Science and Technology**
- Dept. of Marine Science

**Major Contractors**
- Pratt and Whitney Rocketdyne
- Jacobs Technology Inc. – Facilities Operations
- Lockheed Martin IS & GS – Civil - Test Operations Contract
- A2 Research
- ASRC Research and Technology Solutions (ARTS)
- Paragon Systems Inc.
- Science Applications International Corporation
- Science Systems and Applications Inc.

**Commercial Companies**
- Pratt and Whitney Rocketdyne
- Lockheed Martin IS & GS Defense Systems
- Rolls Royce North America

# SSC Resources

## NASA Information Technology Services Contractor

- Historically, operated world-class optics and calibration laboratory
- Experience in:
  - Calibration/validation and modeling expertise
  - Systems Engineering
  - Remote Sensing
  - Chemical and Biological Defense Technologies Experience
  - Instrumentation (Electronics and Optical)

# Brief Overview of Photocatalysis

# Photocatalysis: Development of Technology

- Research into photocatalytic technology has been progressing for over three decades
- Early 1990s
  - Japanese and European companies initiate research into photocatalytic technology
- 1996
  - Specific focus on the technology with the first large-scale application: the construction of a church in Rome (Jubilee Church)
- 2000
  - Europe and Japan research into the benefits of photocatalytic technology
- Currently, photocatalytic technology continues to improve, and with time development is becoming more efficient and effective

# Photocatalysis Principle

What is Photocatalysis?

Photo: phenomenon induced by the light, having specifically a wavelength around 320-400 nm (artificial or natural sunlight)

Catalyst: a material that induces a reaction but is not consumed or transformed by it.

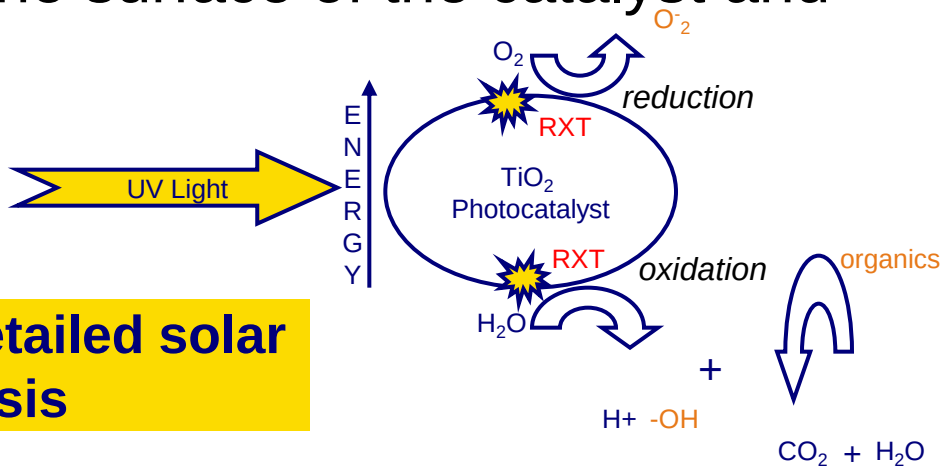
The catalyst remains constantly available.

In this case, the catalyst is made with nano-particles of titanium oxide ($TiO_2$)

# UV Light and Photocatalysis: How it Works

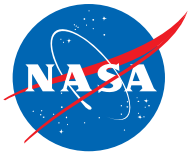


- UV radiation
  - Decomposes many organic and inorganic compounds
  - Slow, natural process
- Photocatalyst
  - Certain materials act as a catalyst for this decomposition process when exposed to UV radiation
- Photocatalytic agents are activated when exposed to **ultraviolet light** (320–400 nm) and water
- RE/DOX reaction occurs at the surface of the catalyst and generates
  - -OH, hydroxyl radicals and
  - $O^-_2$, superoxide ions




**Limited research on influence of detailed solar irradiation on photocatalysis**

# Unique Hydrophilic Properties of $TiO_2$

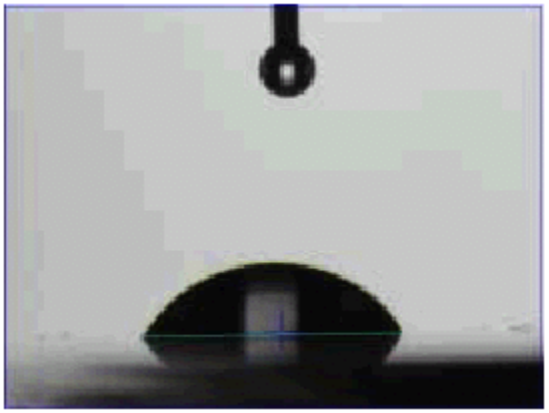



- When exposed to UV light, the contact angle of the photocatalyst surface with water is gradually reduced
- After enough exposure, the surface reaches super-hydrophilicity
  - **the surface does not repel water at all**
  - **water cannot exist in the shape of a drop, but spreads flatly on the surface of the substrate**
  - **water takes the form of a highly uniform thin film, which behaves optically like a clear sheet of glass**

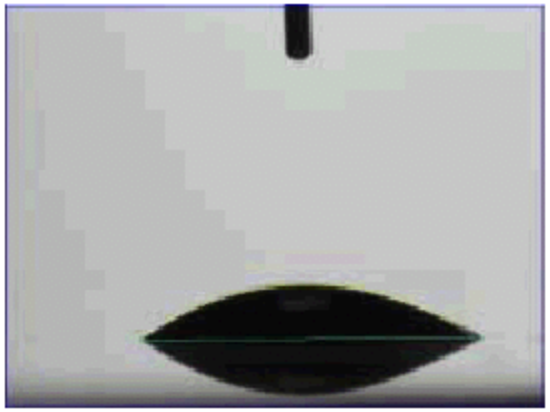
- Application: pollution leaves an oily residue
  - Original building materials include photocatalytic material
  - Coupled with gravity and rainfall, the dirt on the walls will wash away, keeping the building exterior clean at all times (making it self-cleaning)

# Superhydrophilicity

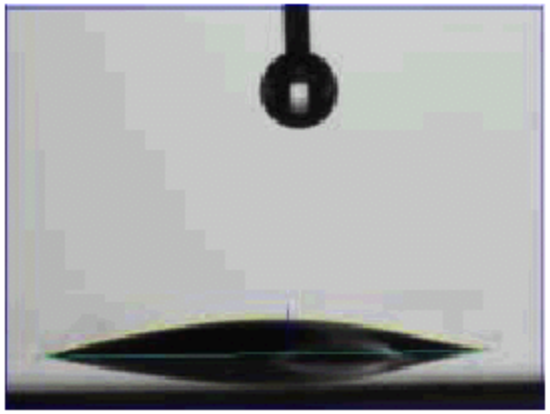
## Before UV Exposure



## 15 mins UV Exposure



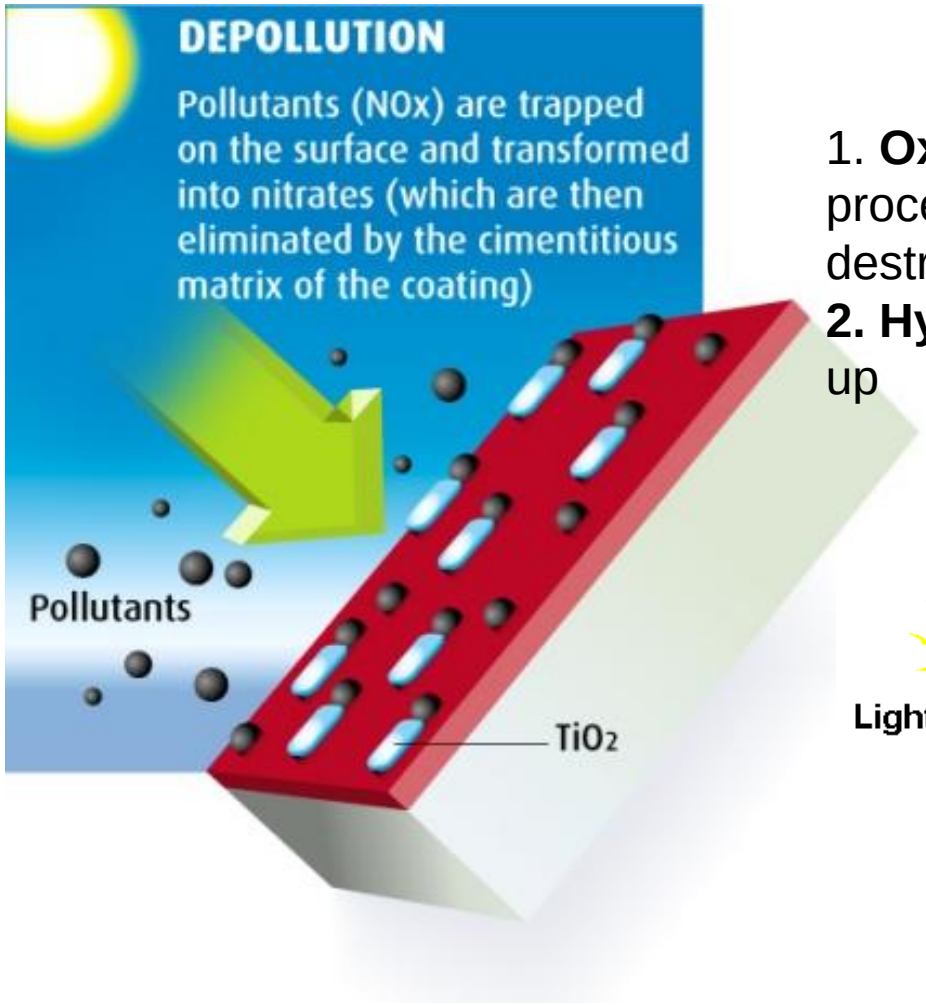
## 30 mins UV Exposure



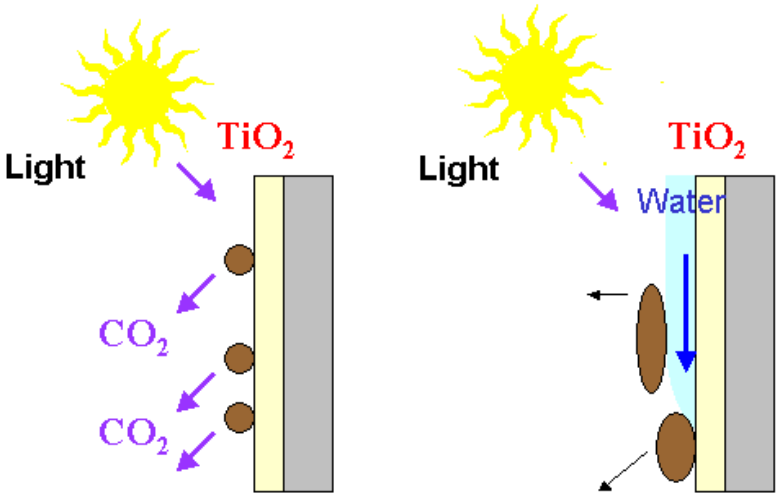
## 45 mins UV Exposure

Source: Pilkington Glass

# The Two Principles of Photocatalysis




1. **Oxidative/reduction** reaction processes-pollutants (and stains) are destroyed
**2. Hydrophilicity** prevents residue build-up



# Commercially Available Photocatalytic Self-Cleaning Materials

- Cement & Concrete Pavers
- Tiles
- Glass
- Spray-on Coatings
  - “Spray-on” coating services
  - “Spray-on” coatings for purchase
- Nanomaterials
  - Nanoparticles for purchase

# $TiO_2$ Use and Cost Comments

- Use
  - These surfaces are in fairly wide use throughout Japan, and are being marketed in Europe
  - *Many of these products have not yet reached the U.S. market*
- Cost
  - The cost to transform the facade of a five-story building into a photocatalytic surface would add approximately 100 euros, $120, to the cost of traditional cost of paint or plaster.
  - Paving a street or sidewalk might be a little more costly-but not excessively.
  - The Italian cement products are 30-40% more expensive than regular concrete
  - No significant price difference between regular and enhanced tiles

# Photocatalytic Material Companies

Cement:

- Essroc Italcementi Group, **TxActive®** Cement
- www.italcementi.it

Tile:

- TOTO, **Hydrotect** Tiles
  http://www.toto.co.jp/hydro_e/index.htm
  http://www.toto.co.jp/products/hydro/genri_en.htm
- DSA Ceramics/Agrob-Buchtal, **Hydrotect** Tiles,
  http://www.agrob-buchtal.de/chroma/e/chroma/seite_17.html
  http://www.agrob-buchtal.de/dscb_abo_site/en/hydrotect_new/the_solution.html?pe_id=106&pe_id=108

Glass:

- PPG Industries, PPG Glass**, SunClean**™ Glass
  http://corporateportal.ppg.com/NA/Glass/ResidentialGlass/Homeowners/ProductInformation/SunClean/
- Pilkington Glass, **Pilkington Activ**™ Glass
  http://www.pilkington.com/international+products/activ/default1.htm

# Photocatalytic “Spray-on” Coatings

- Bioshield, http://thecleanairdoctor.com/bioshield__titanium_dioxide_
- Enviroclean, http://www.teamenviroclean.com/home
- Green Millennium, http://www.greenmillennium.com/
- Green Titan, Inc., http://www.greentitan.com/
- Innovative Sealing Solutions, Inc., http://www.innovativesealingsolutions.biz/
- Kon Corporation, http://www.saga-kon.co.jp/english/about_kon.html
- Nanocepts, Inc., http://nanocepts.com/index.html
- Oxytitan, http://www.oxititan.com/
- Nanotec-USA, http://www.nanotec-usa.com/
- Schenzhen Become Industry and Trade Co., Ltd., http://www.root-cn.com/
- TioxoClean, Inc., http://thegreenconcept.com/tioxoclean.html
- Titan Technologies, http://www.titantechnologies.biz/Literature.htm
- Tinanystar, http://www.yield-kyoto.com/English/Titanystar/index/e-index.htm

# TxActive® Cement in Italy

- Jubilee Church had white coating in the concrete to preserve the whiteness
- Six years later, the coated concrete is as white as it was when constructed, while other parts of the building have grayed because of atmospheric pollution

Source: http://www.italcementigroup.com/ENG/Media+and+Communication/News/Building+and+Architecture/20031126.htm

# Photocatalytic Cement Road Italy

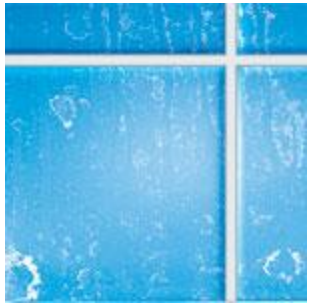
- In a test in 2003, the company coated 75,000 square feet (6,750 square meters) of road surface on the outskirts of Milan with photocatalytic cement
- Nitrogen oxide levels were reduced by up to 60 percent, depending on weather conditions

Source: http://www.technologyreview.com/Wire/14569/

# DSA-Ceramics/Agrob-Buchtal/Hydrotect

## Uncoated tile:

Water droplets form



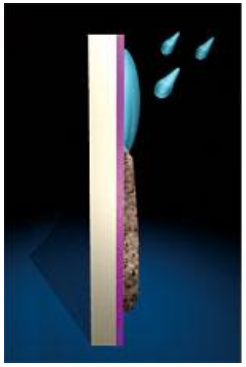
Dirt and lyme Is left after drying

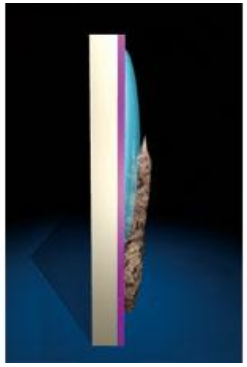
HYDROTECT

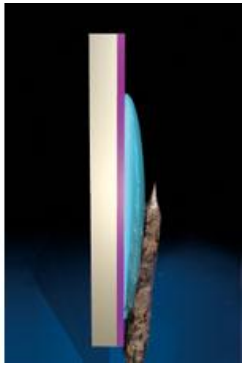
## Hydrotect tile:

The water spreads as a thin film on the surface And lifts dirt form the Surface. Water droplets form . . .

... which can then be easily removed.
Result: a clean surface



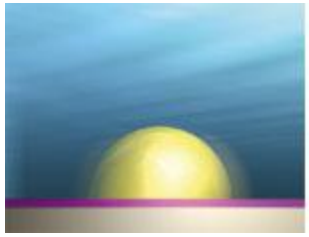


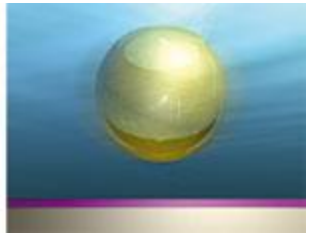


Oil and grease detach from the surface.

## *No chance for dirt, oil and grease*

With Hydrotect, dirt is washed down by the water and can then be easily wiped off.





Source: http://www.agrob-buchtal.de/dscb_abo_site/en/hydrotect_new/the_principle.html?pe_id=110

# Hydrotect Technology - Hydrophilicity

## Comparison of wettability

Ordinary ceramic tile surface

Ceramic tile surface coated with super-hydrophilic photocatalyst

Source: http://www.toto.co.jp/products/hydro/genri_en.htm

# Hydrotect Technology - Decompostion

Decomposes various organic substances, which prevents the growth of bacteria, algae, mold, germs, and dirt retention

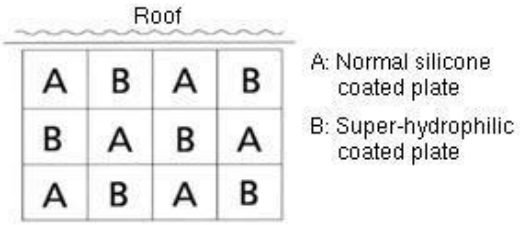
HYDROTECT

Super hydrophilic photocatalyst technology + Photocatalytic organic decomposition technology

Sources: http://www.toto.co.jp/products/hydro/genri_en.htm
http://61.114.182.22/products/hydro/genri_en.htm

Source: http://www.toto.co.jp/hydro_e/hydro_e4.htm

Exposed outside for 3 weeks



Exposed outside for 1 year

Fig. 7 Difference of self-cleaning ability by a rainfall between the super-hydrophilic coated plates and the normal silicone coated plates

# Marunouchi Building in Japan

Covered with Hydrotect photocatalytic tiles to reduce discoloring from pollution

HYDROTECT

Sources: http://61.114.182.22/docs/hyd_patent_en/case_001.htm
http://web-japan.org/trends/science/sci040319.html

# Muhammad Ali Center in USA

HYDROTECT

# SunClean® Glass, PPG Industry

- **Self-Cleaning Window Glass Technology**

  The self-cleaning property of SunClean® glass is made possible by a titanium dioxide ($TiO_2$) applied during the manufacturing process

  - applied to hot glass during the forming process to form a strong, long-lasting bond, which makes the coating an integral part of the outer glass surface

  The coating has photocatalytic and hydrophilic properties

  When rain or a light spray of water hits the window, the water carries away the loosened dirt

  Sheeting action also helps the window dry quickly with minimal spotting or streaking

Source: http://corporateportal.ppg.com/NA/Glass/ResidentialGlass/Homeowners/ProductInformation/SunClean/SunCleanHowItWorks.htm

# SunClean® Glass vs. Conventional Glass

- The coating's hydrophilic property makes water droplets spread out, or sheet, across the surface of the glass.

- When rain or a light spray of water hits the window, the water helps to more effectively
- rinse away loosened dirt.

- This sheeting action helps the window dry quickly with minimal spotting and streaking.

conventional glass

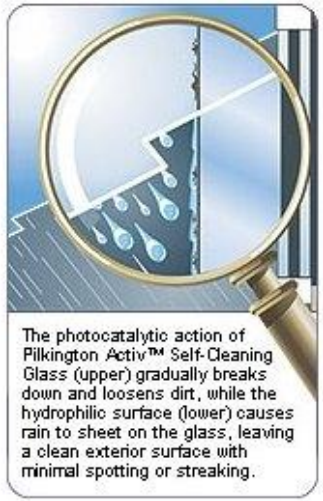
SunClean® glass

Source: http://corporateportal.ppg.com/NA/Glass/ResidentialGlass/ResidentialBuildersRemodelers/ProductInformation/SunClean/Sheet+Action+Big.htm

Source: http://corporateportal.ppg.com/NA/Glass/ResidentialGlass/Homeowners/ProductInformation/SunClean/SunCleanHowItWorks.htm

# Pilkington Glass-Pilkington Activ™

- Only reduces the amount of sunlight passing through by only about 5%
- coating is very tough and would require real abrasion, i.e. scrubbing with steel wool, to remove it
- dirt.
- the surface of the glass is hydrophyllic - rather than beading up (and drying in blotches), water forms a sheet that allows organic dirt particles to flow off and then the glass dries without streaks.




Source: http://www.pilkingtonselfcleaningglass.co.uk/pilkingtonactiv

# Titanium dioxide coatings in Tokyo

- In MTR stations, commonly touched surfaces have been coated (i.e., escalator handrails, buttons on ticket-issuing machines, and elevator buttons)

# Photocatalytic Surface Materials Studies

# On-site Testing and Applications: Preliminary Studies

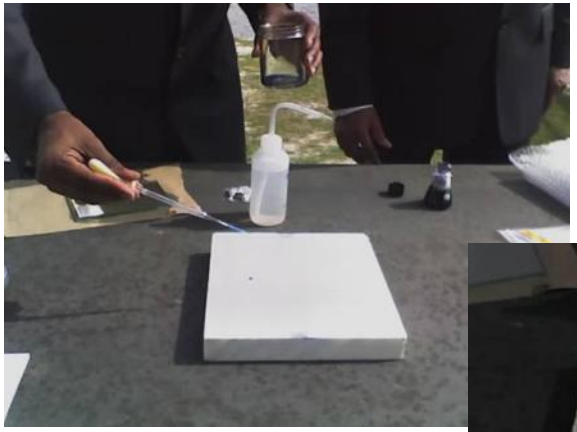
# Nanocept, Inc.

- Primary business line is the manufacture and production of **photocatalytic coatings** based on advanced materials with an emphasis on $TiO_2$
- They partner with research institutions, national laboratories, and specialized industries to engage themselves as a strong technology provider in the area of photocatalysis

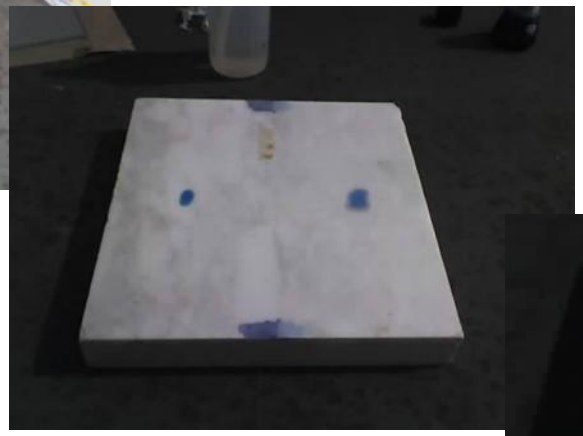
- Demonstrations
  - Methylene Blue dye
  - Odor absorbing
  - Red/ink dye test
  - Hydrophilicity

# Self-Cleaning Reduces Maintenance Costs

Clean marble

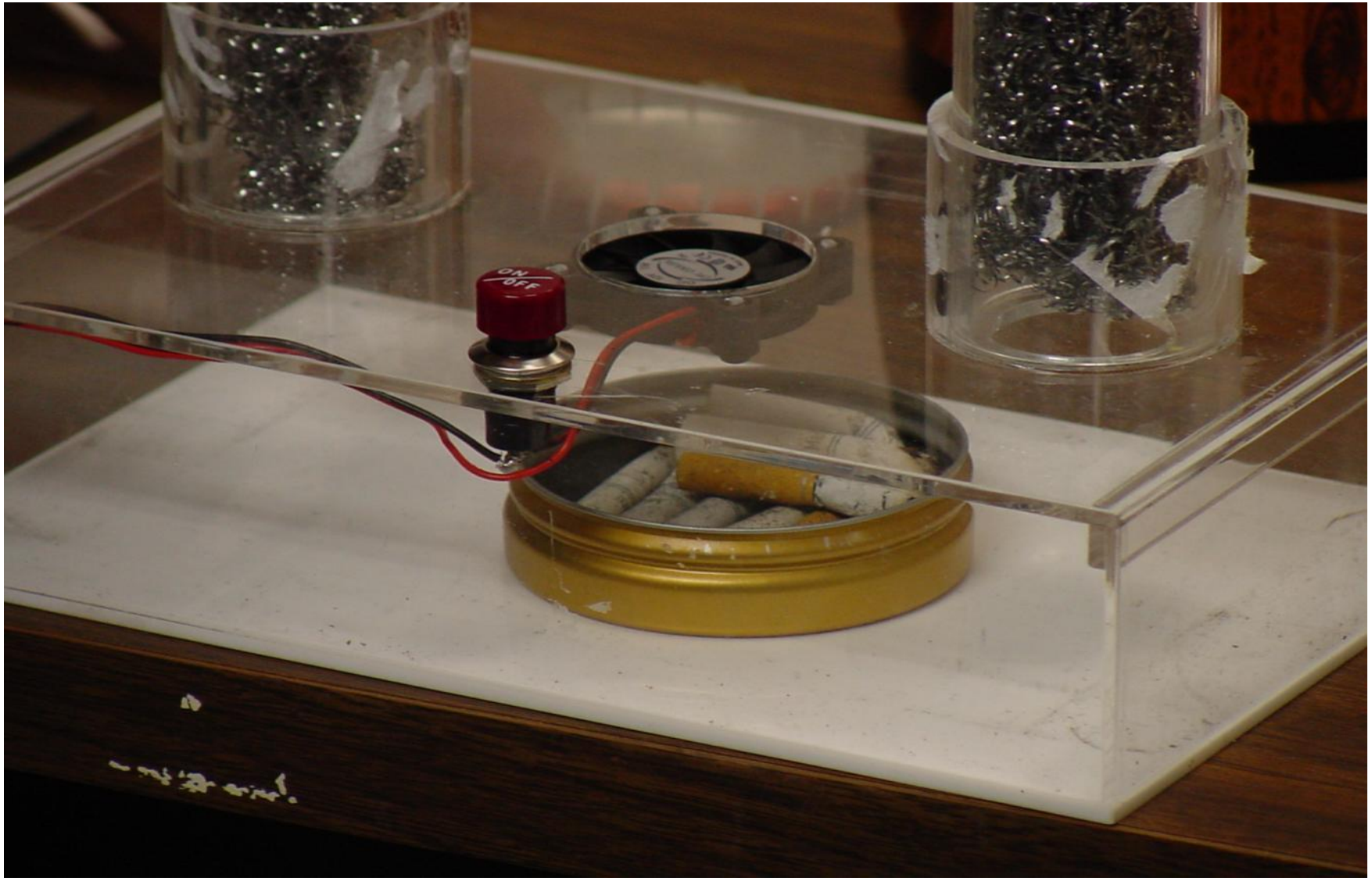


Methylene blue
application on clean marble



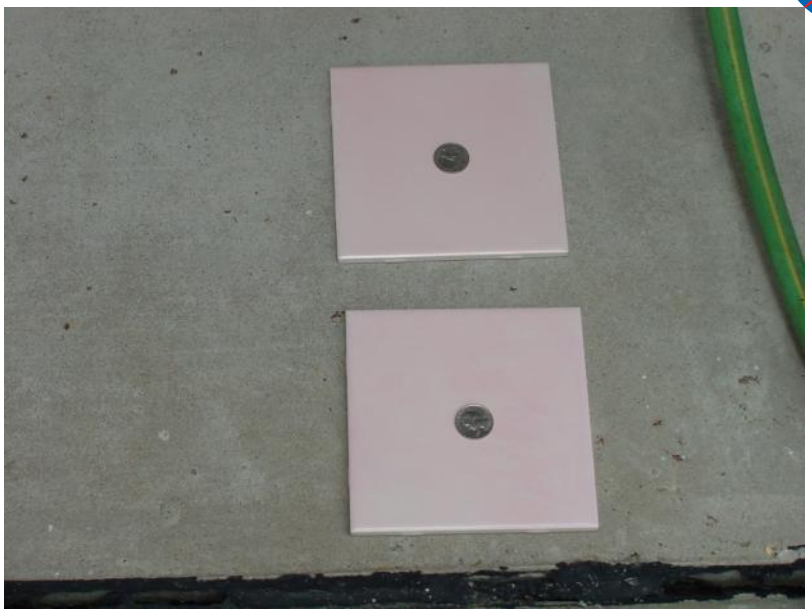
Methylene blue dye
after 1 hour in the sun

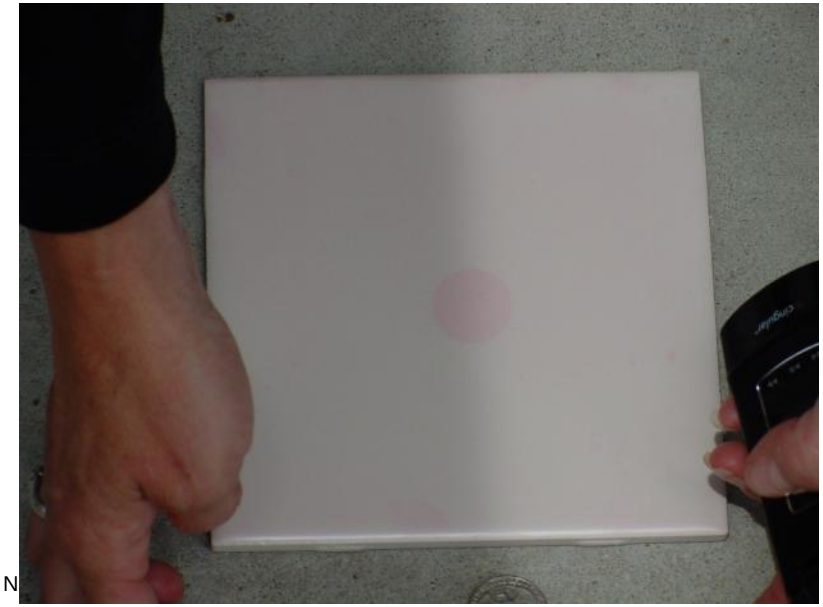
# Odor Absorbing

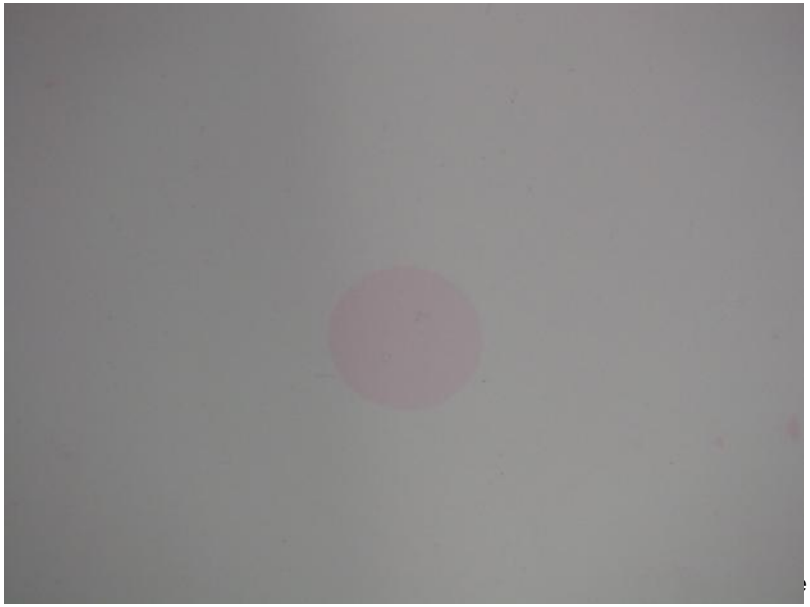


# Red Ink Dye Test

# Red Ink Dye Test







# Superhydrophilicity

# Test Application 2006: Before $TiO_2$ Coating Application

# Test Application 2006 On-Site: During

*Stennis Space Center*

# Test Application On-Site: After

Stennis Space Center

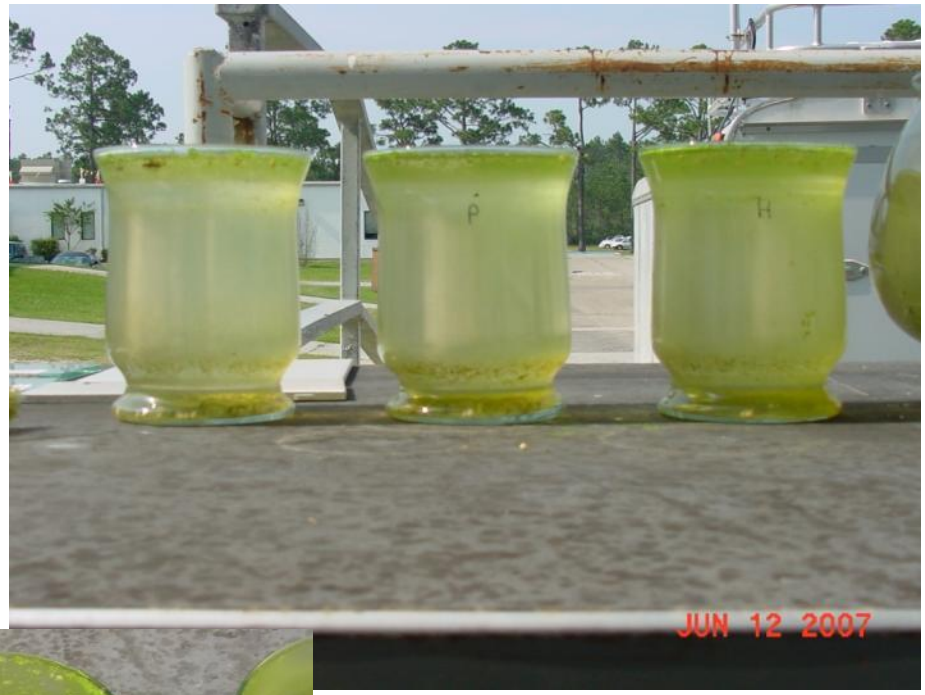
# Building 2012

–NO–
PARKING
2206

# Pilot Experiment: Hydrotect Tiles

*Stennis Space Center*

# Pilot Experiments: PCGlass



# Pilot Experiment: PCGlass

# Pilot Experiment: Hydrotect Tiles

# Pilot Experiment: Hydrotect Tiles

**Location: Spillway**

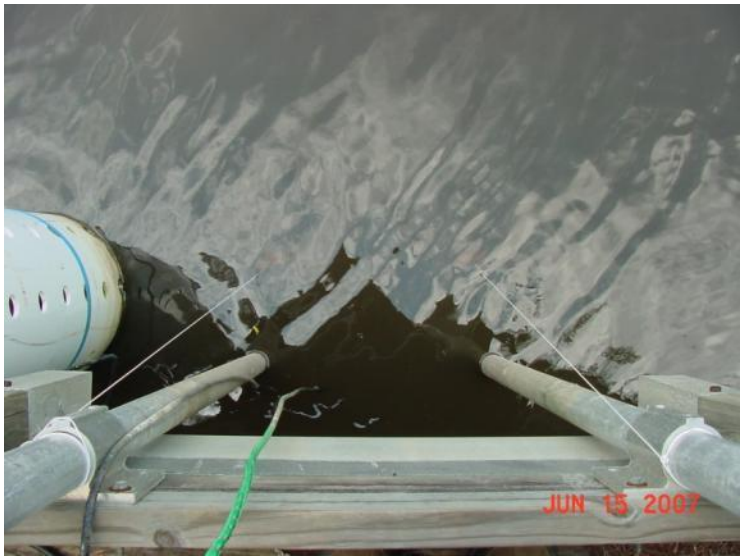
# Pilot Experiment: Hydrotect Tiles

Stennis Space Center

**Location: Spillway**

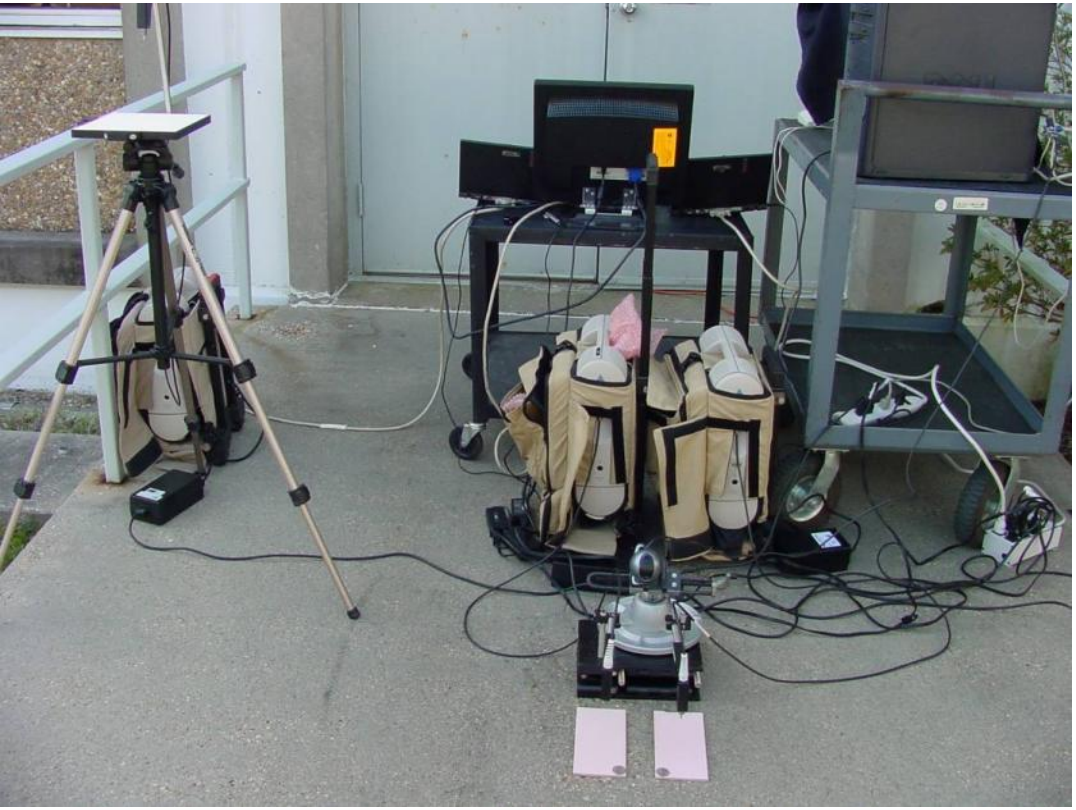
# Pilot Experiment: Hydrotect Tiles

**Location: USGS dock**



# Stain Decomposition Spectral Reflectance Measurements over Time

Test set-up showing spectral radiometers and tiles



Spectralon reference panel

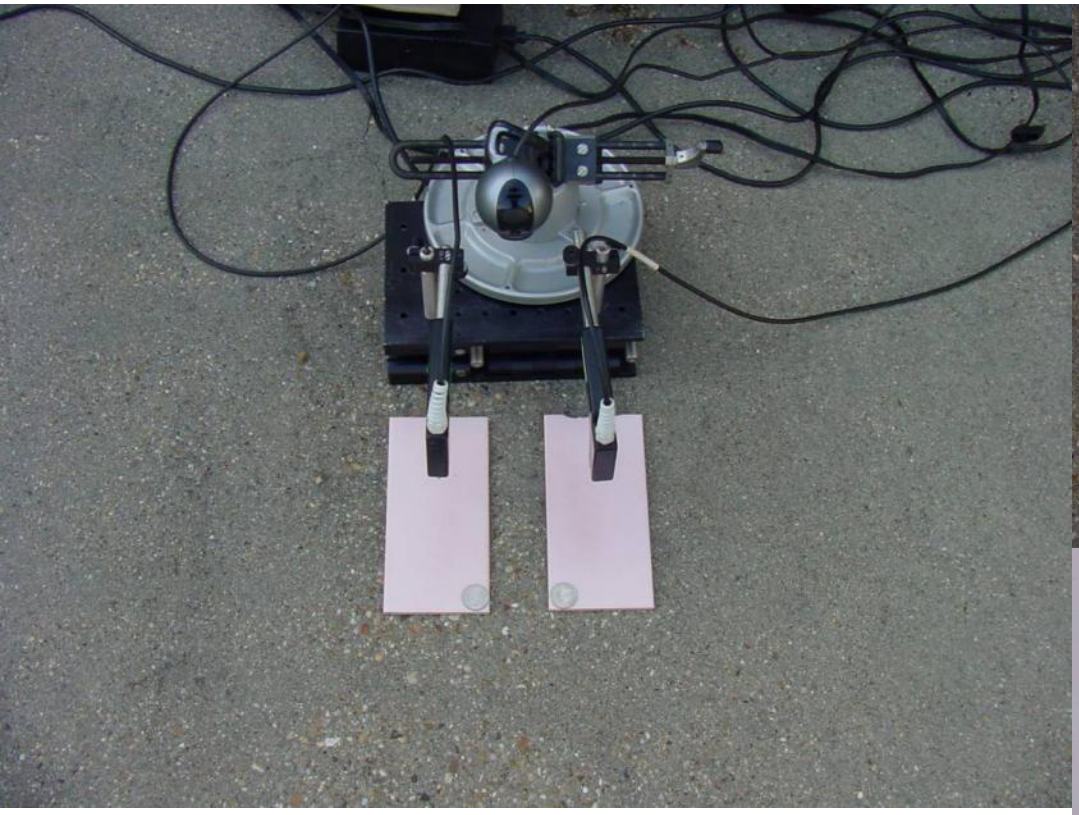
# Spectral Reflectance Measurements

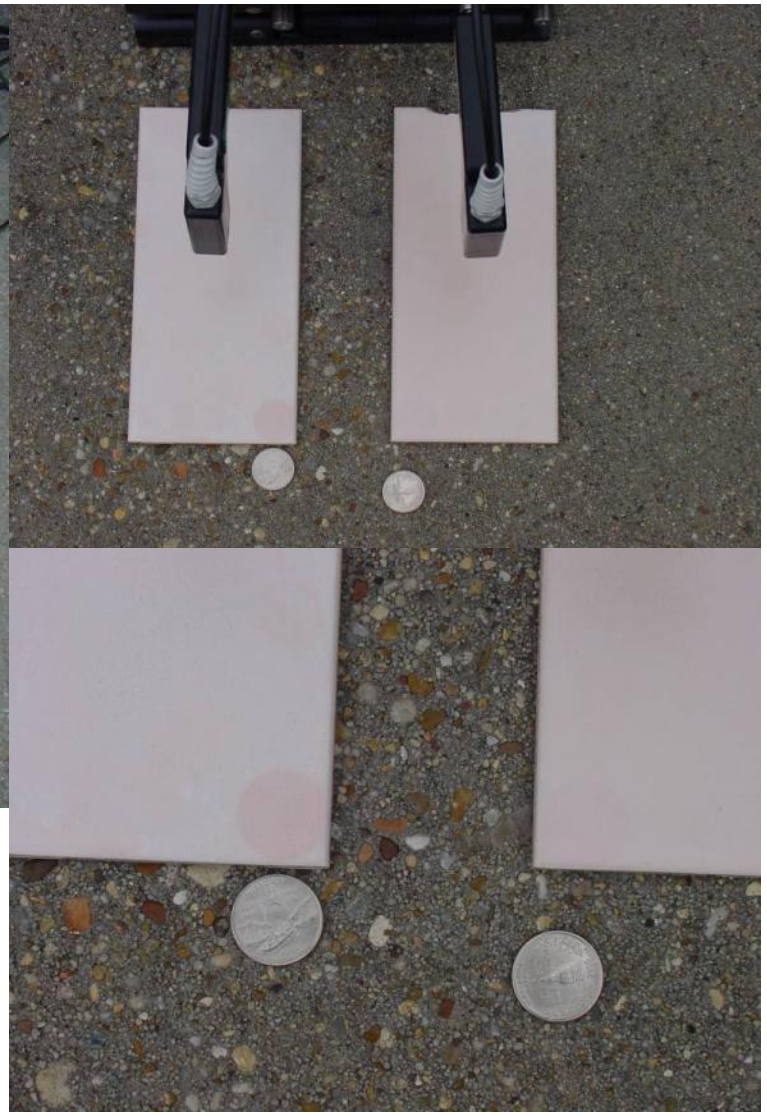
- Purpose:  to show that the absorbance curve of the red dye decreases over time
- Method: use three separate spectroradiometers to compare the spectral curves, over time, of the  following:
  - Tioxoguard/tioxoclean coated tile
  - Plain uncoated tile
  - Spectralon panel

# Stain Decomposition Spectral Reflectance Measurements over Time



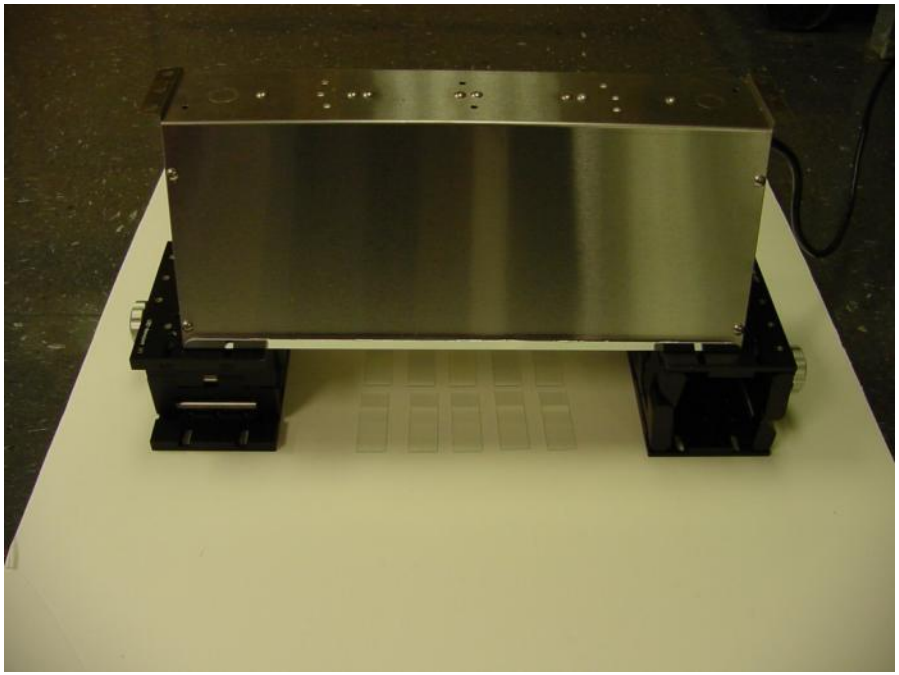
After exposure to sunlight

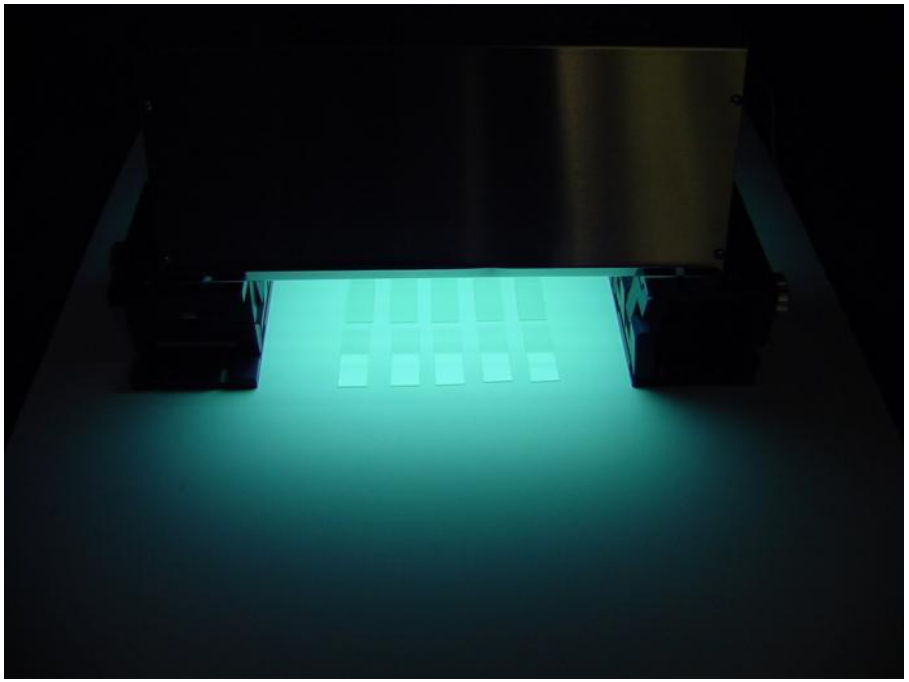




Initial set-up with spectral radiometers fiber optics
Left: Tioxoguard/Tioxoclean coated tile + food dye
Right: uncoated tile + food dye

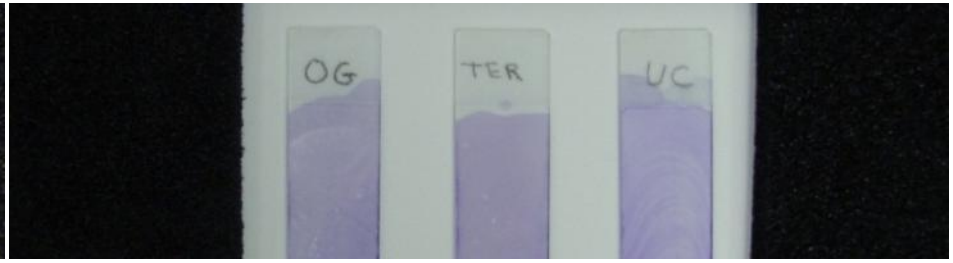
# Black Lamp Sample Cleaning and Charging



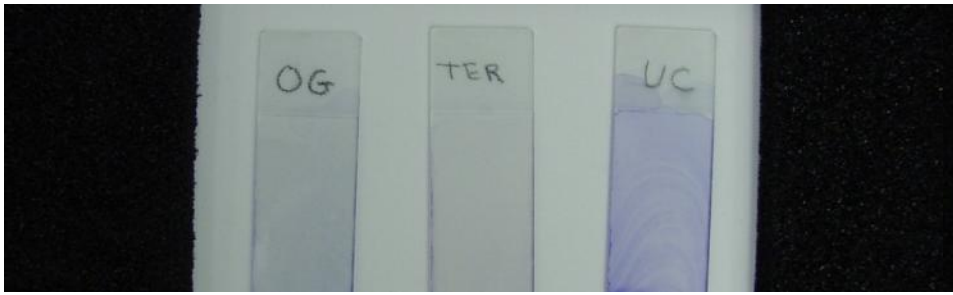


# Demonstration

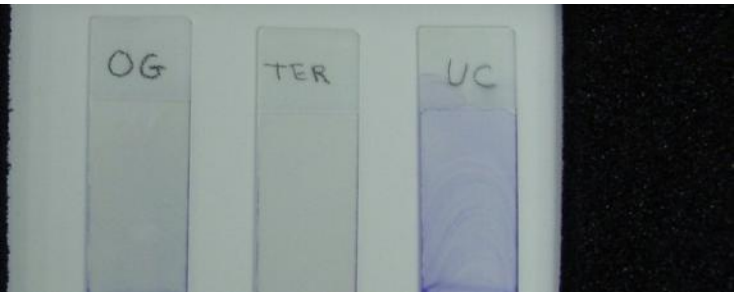
*Pre-dye application*




*Post-dye application*



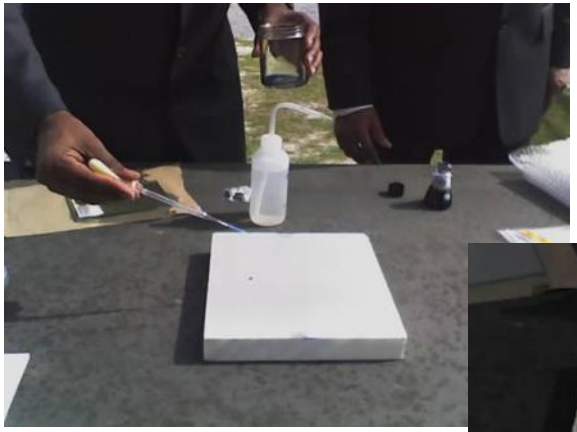

*1 hour UV exposure*



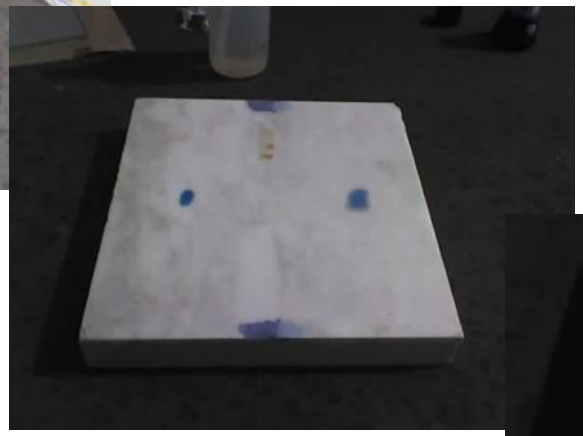

*1.5 hour UV exposure*

# Stain Decomposition Test-Methylene Blue

***Clean marble***



***Methylene blue application on clean marble***



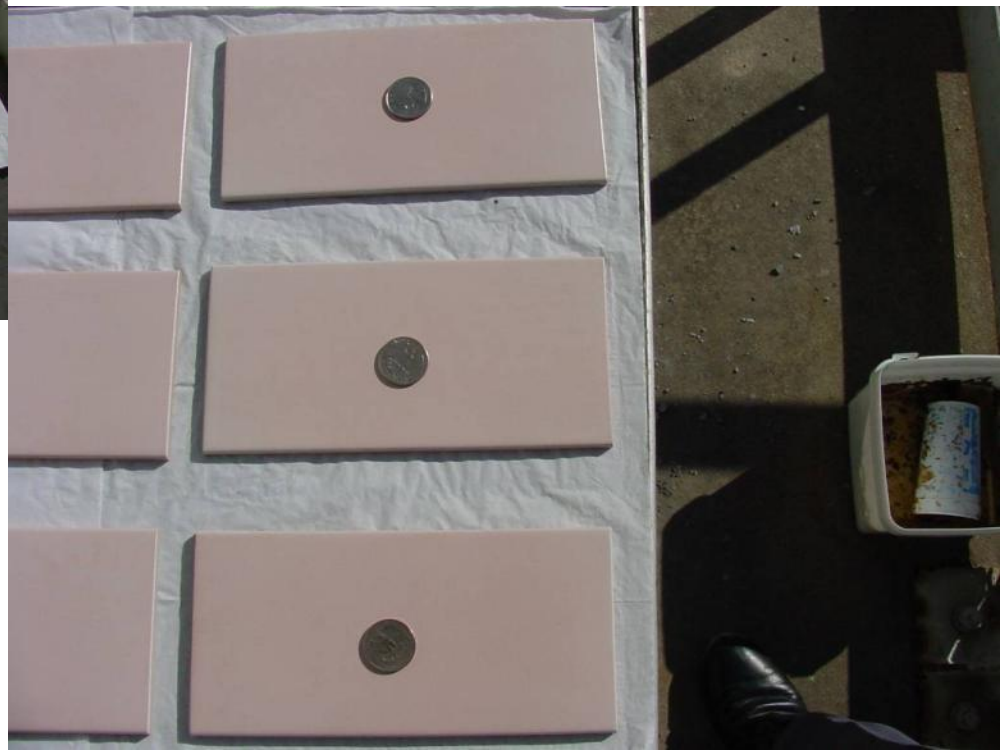
***Methylene blue dye after 1 hour in the sun***

# Stain Decomposition Test-Red Food Dye

***Far left: hydrotect tile***
***Middle: plain tile***
***Right: tioxoguard/tioxoclean coated tile***

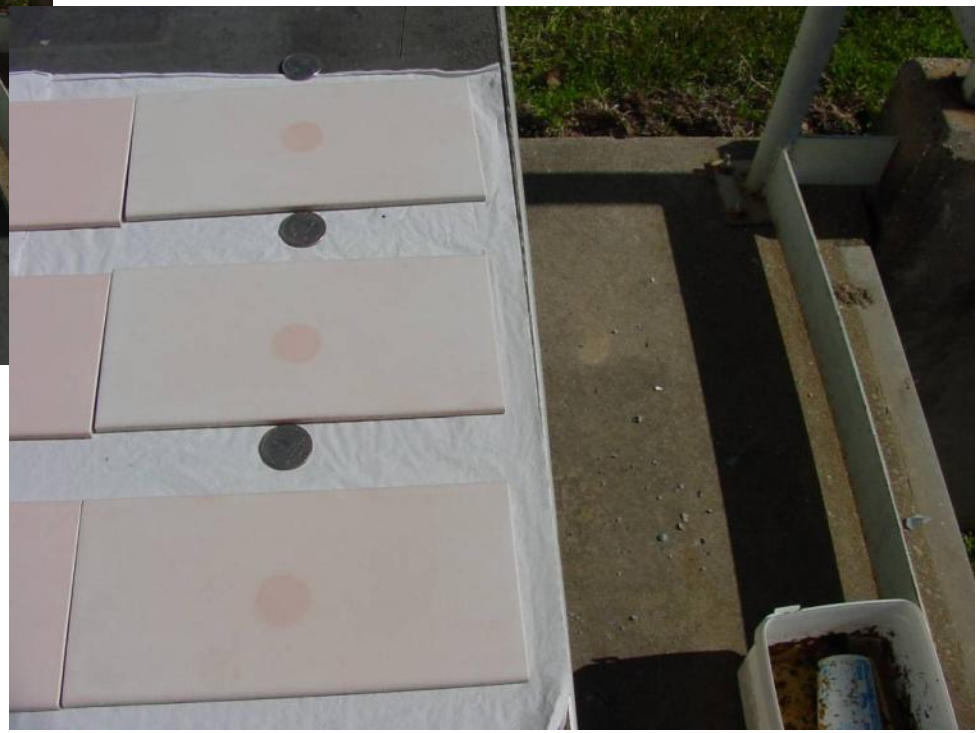
***Far left: hydrotect tile + red food dye***
***Middle: plain tile + red food dye***
***Right: tioxoguard/tioxoclean coated tile + red food dye***

# Stain Decomposition Test-Red Food Dye



***Quarters placed on tioxoguard/tioxoclean coated tiles***

# Stain Decomposition Test-Red Food Dye

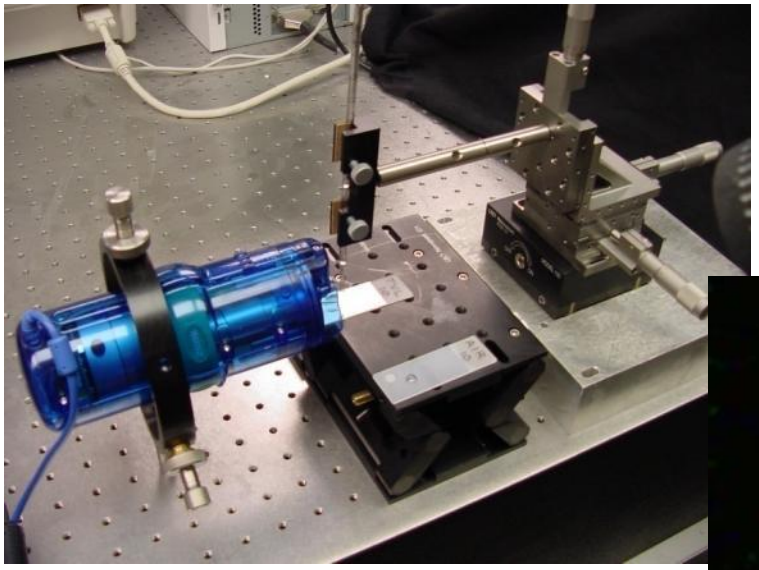


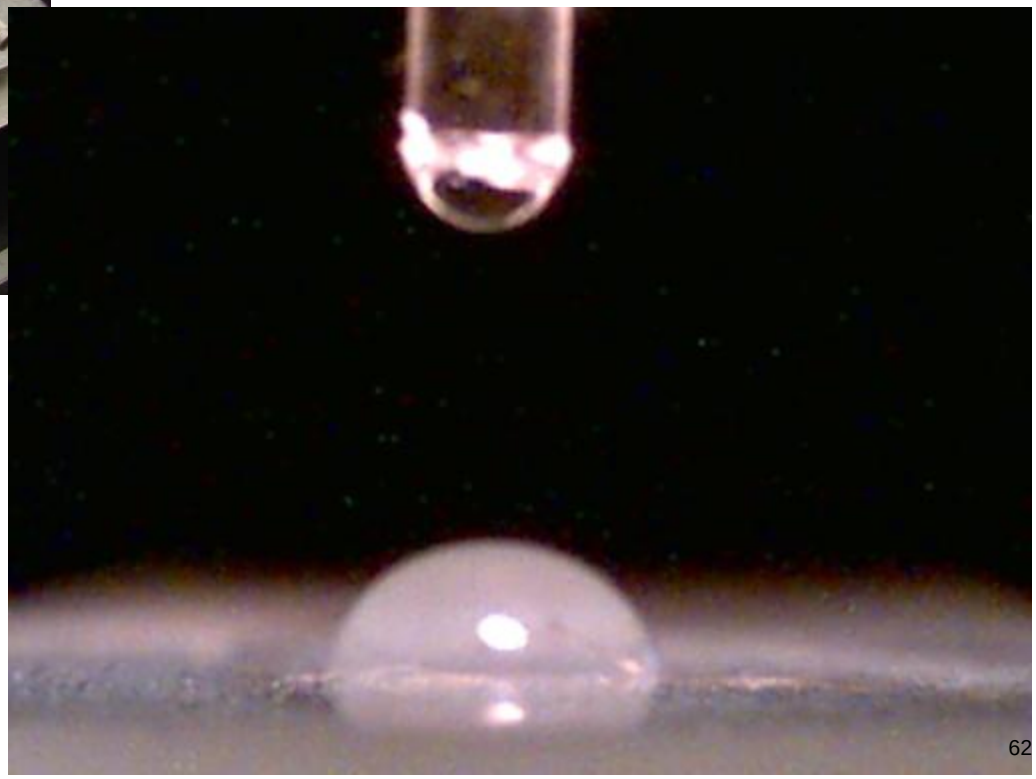
***3hrs later, after all tiles have been exposed to direct sunlight***

# Photocatalyst: Hydrophilic Properties

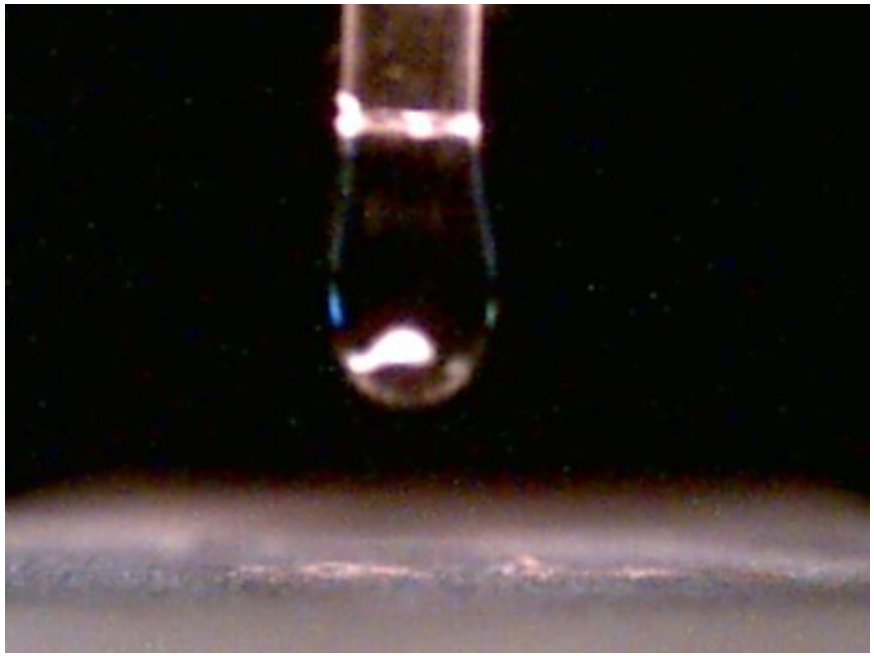
- As photocatalytic materials are exposed to UV light, the contact angle of that surface with water is reduced gradually
- After enough UV exposure, the surface reaches super hydrophilicity
  - Water becomes a highly uniform thin film, which behaves optically like a clear sheet of glass
- Coupled with gravity and rainfall or assisted washing, the contamination on surfaces is removed making it self-cleaning

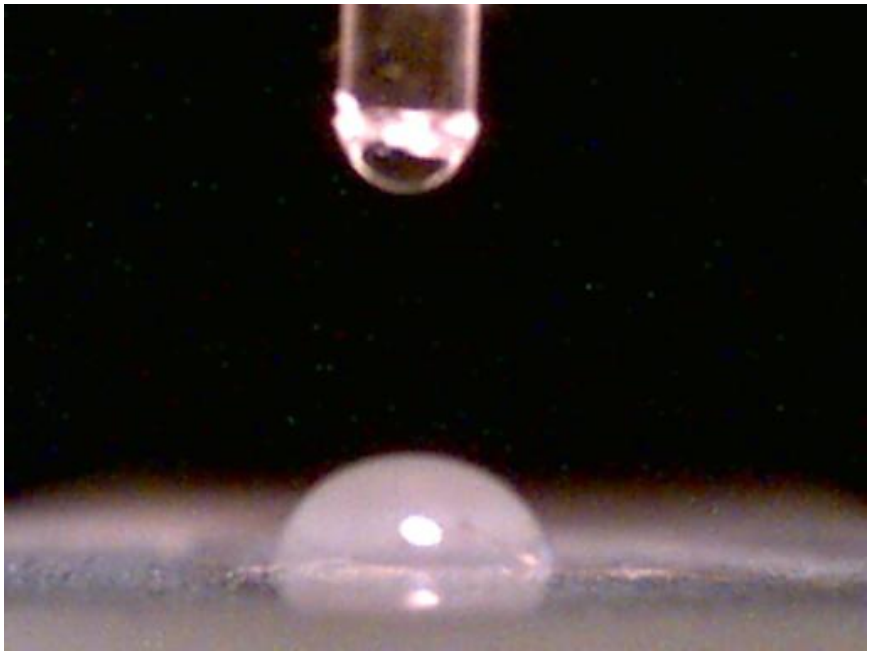
# Contact Angle Measurement





# Non-hydrophilic





Water forms a droplet

# Superhydrophilic Photocatalytic Coating

Contact angle vanishes completely,
Water forms a flat sheet

**Non-hydrophilic** side-
water forms droplets

**Superhydrophilic side-**
water forms sheets



Source: http://www.rcboataholic.com/faq/hull_finish.htm

# Photocatalytic Surface Materials Studies: Funded Projects

# Investigating Commercially Available Photocatalytic Materials and Coatings for Protecting Infrastructures Against Terrorism Threats

Bruce A. Davis (DHS)

Robert E. Ryan (Innovative Imaging & Research)

Lauren W. Underwood (Science Systems and Applications, Inc.)

May 29, 2009

Homeland Security

# Objective

- Survey and compilation of a list of commercially available photocatalytic building materials.
- Establish standard methods for a photocatalytic material illumination system
- Investigate the superhydrophilic properties of photocatalytic materials
- Evaluate the photodecomposition of dyes, organophosphate simulants, and biological materials

# Approach and Results



## Approach

- A time series analysis was used to quantify the rate of photocatalytic toxic simulant degradation.
- A stable light source was developed that used a quantifiable approach to measure dye breakdown.
- A standard analytical chemistry approach –gas chromatography (GC).
- A standardized analysis (developed in Japan) for biological evaluation of photocatalytic degradation.
- Contact angle measured for evaluation  and assessment of hydrophilicity

## Results

- Compiled a database of currently available commercially available photocatalytic materials.
- Coatings demonstrated a superior photocatalytic degradation capability compared to other material and could be used to retrofit onto existing infrastructure
- Photocatalytic surfaces decomposed dye material faster than uncoated surfaces but was dependent on the illumination intensity
- Organophosphate material had 96% degradation after 2 hours and 98% after 6 hours on photocatalytic surfaces
- Vegetative bacteria mortality rates were greater on photocatalytic surfaces.
- Bacterial spores demonstrated resistance to test methods
- All photocatalytic coatings demonstrated super hydrophilicity during and after illumination

# Conclusions

- Reasonably cost photocatalytic building materials exist today
  - Under bright illumination conditions, these materials could mitigate chemical and biological toxic material.
  - Low light and different illumination environments appear promising, but requires further research.
- The hydrophilic property of the photocatalytic surface permits much easier cleaning of contaminated surfaces. Latency effect of photocatalytic material properties needs investigation.
- Standard methods for evaluation of photocatalytic material performance under varying illumination conditions needs further development
- Currently, international collaboration –without a US contingency-is engaged in the development of standards for photocatalytic materials. There is a distinct lack of emphasis on a wide range of environmental conditions with respect to these materials. The US should leverage this effort and assist in the development of standards.

# Photocatalytic Dye Breakdown Experiment

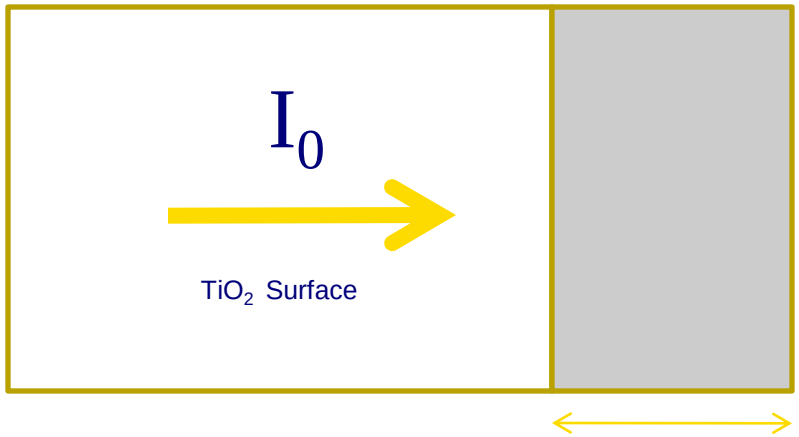
December 1, 2008

# Dye Experiment

- Time series transmission spectra are taken to determine photocatalytic reaction rate
- Simple standardized method for rapidly screening photocatalytic coatings
- Crystal Violet dye used to assess degradation capability
- UV simulator black lamp from GE
- Rapid method for evaluating photocatalytic materials function/efficacy

# Transmission

$$I = I_0 \exp(-\alpha z)$$




## Transmission

$$T = \frac{I}{I_0}$$

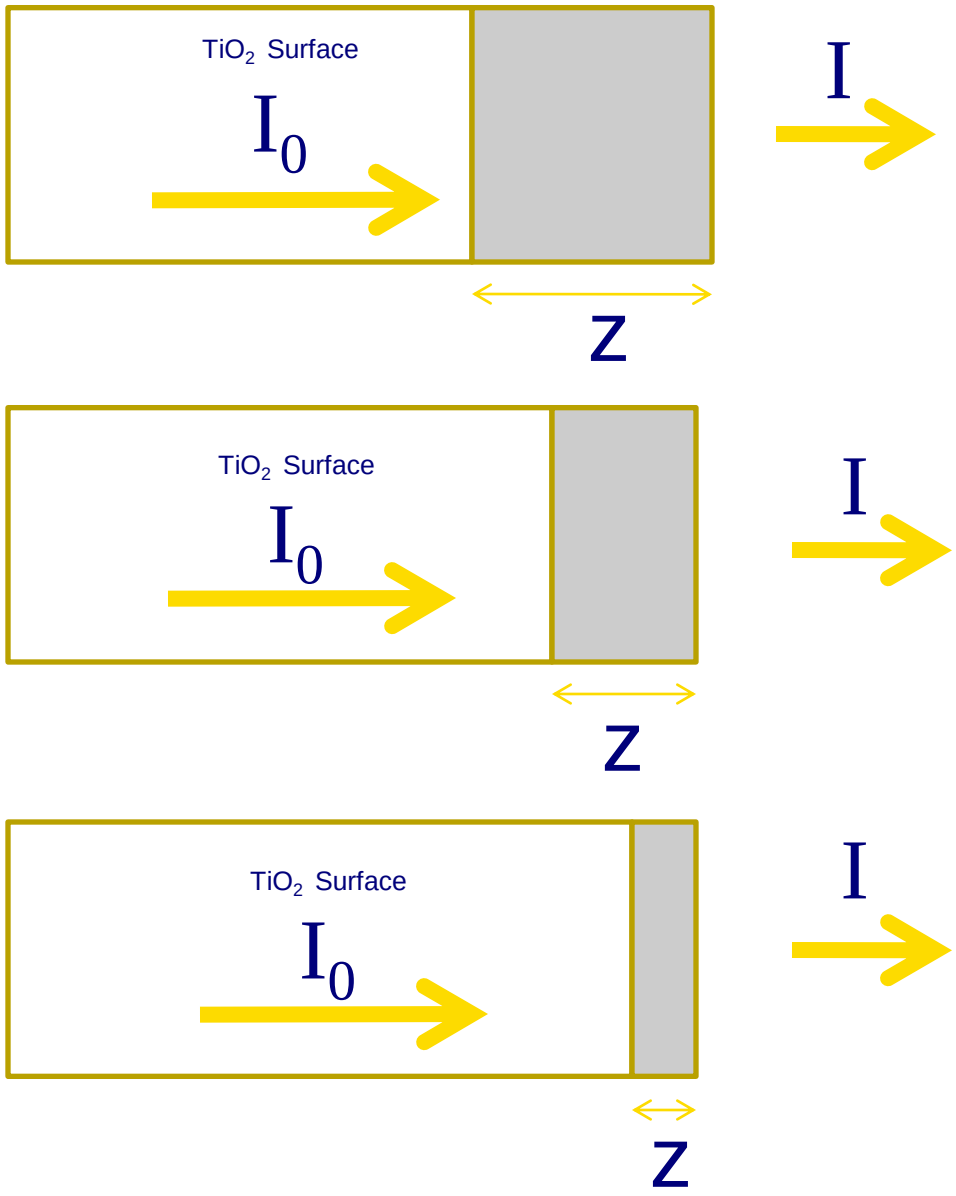
Z is the thickness of the dye

I is irradiance/output

$I_0$ is the reference/input

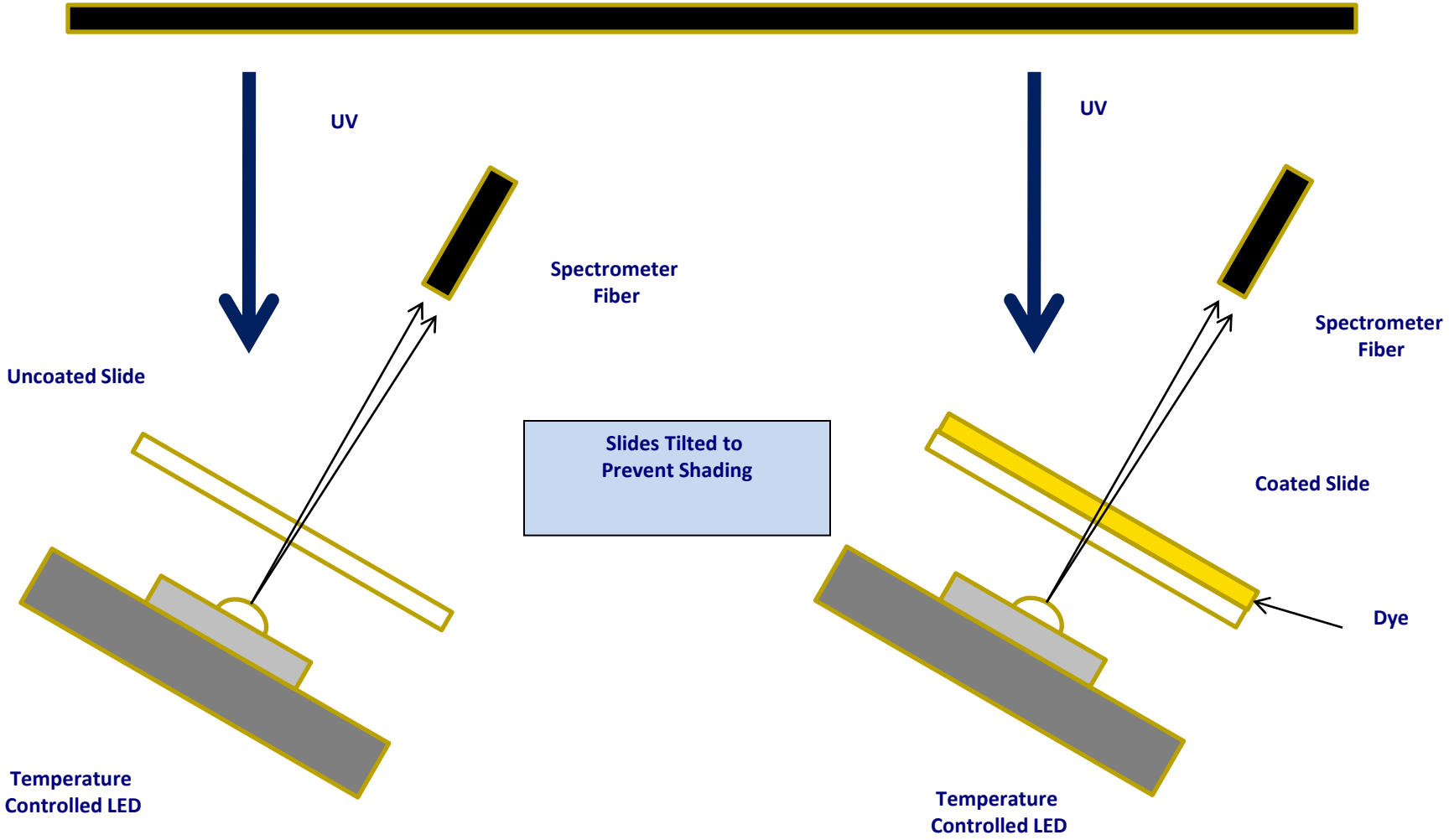
*Based upon Beer-Lambert Law there is a logarithmic dependence between the transmission (or transmissivity), *T*, of light through a substance and the product of the absorption coefficient of the substance, $\alpha$

# Dye Breakdown



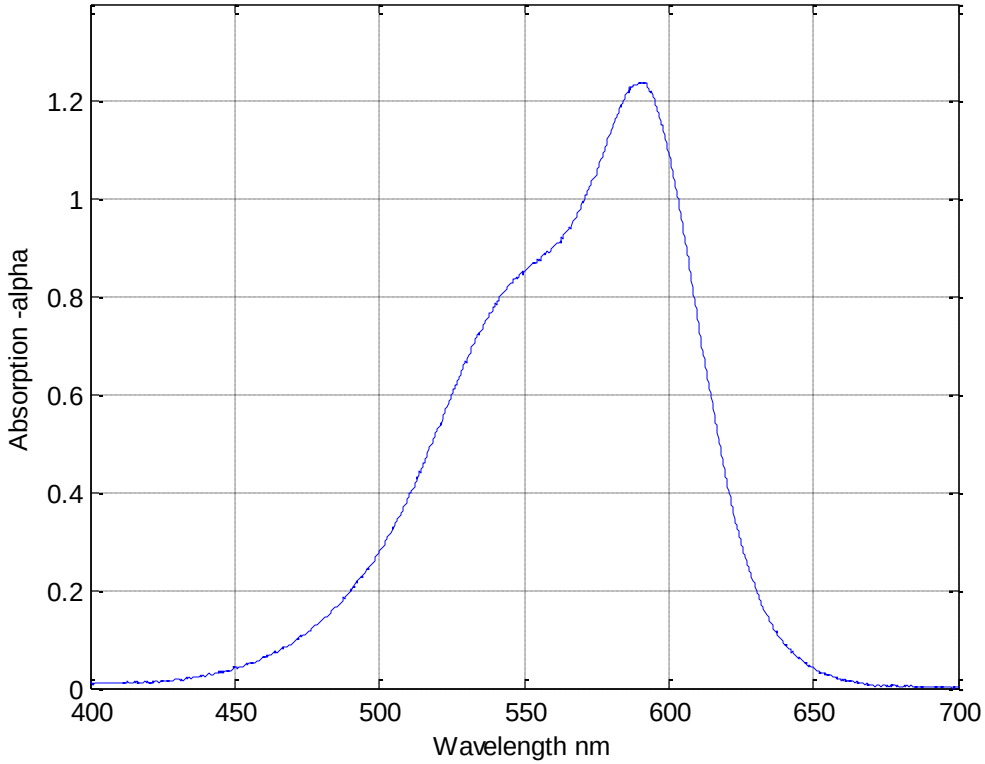

Transmission will increase as the dye breaks down

# Transmission Experiment Schematic



# Crystal Violet

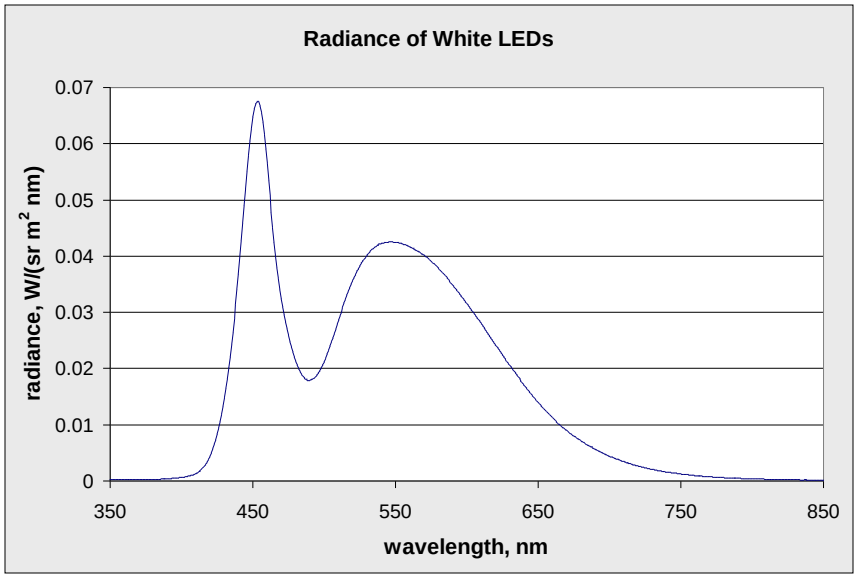
- Absorption is in the visible light wavelength
- Relatively insensitive to UV photodissociation



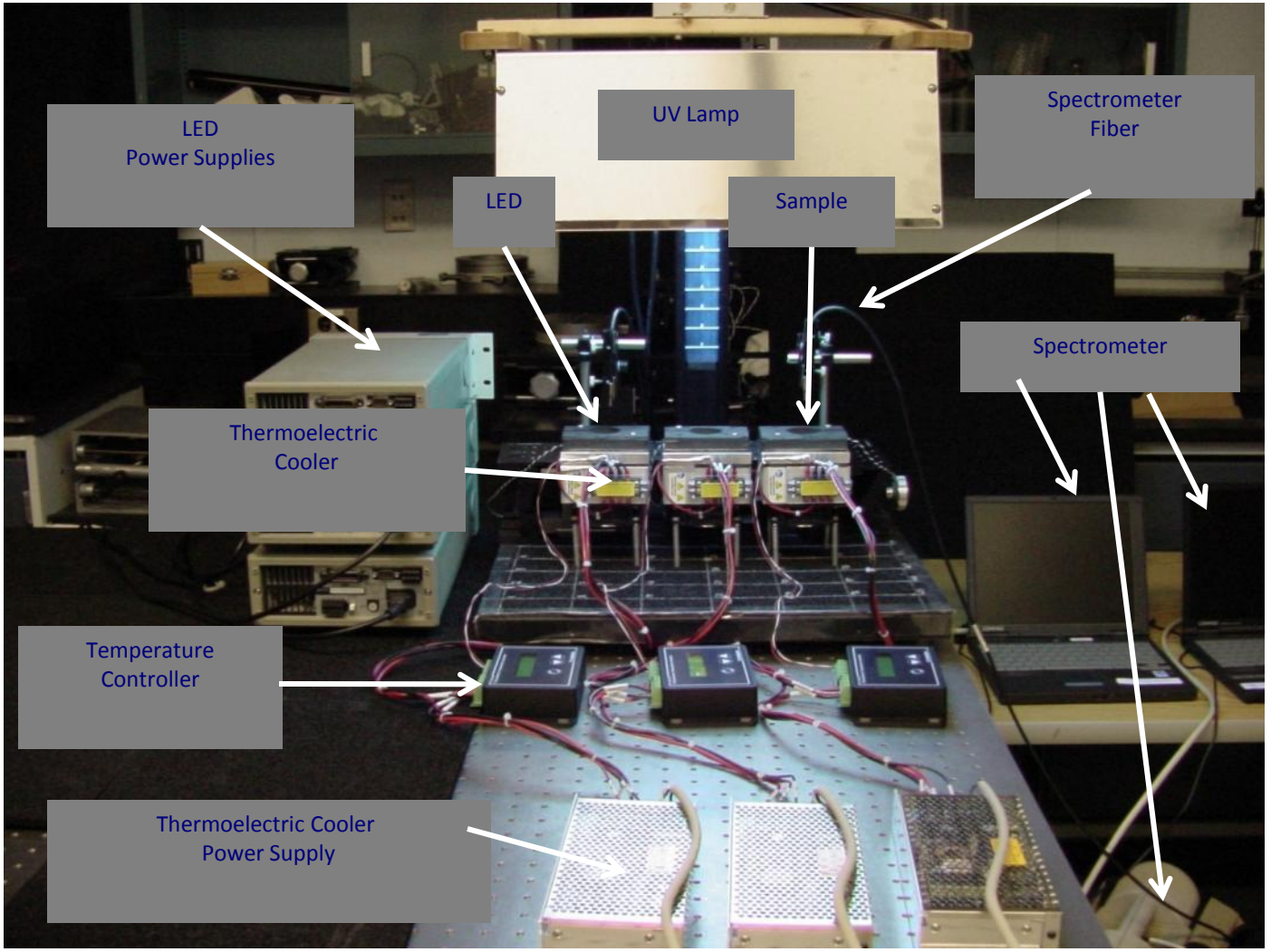

Absorption Spectra

# Reference White Light LED

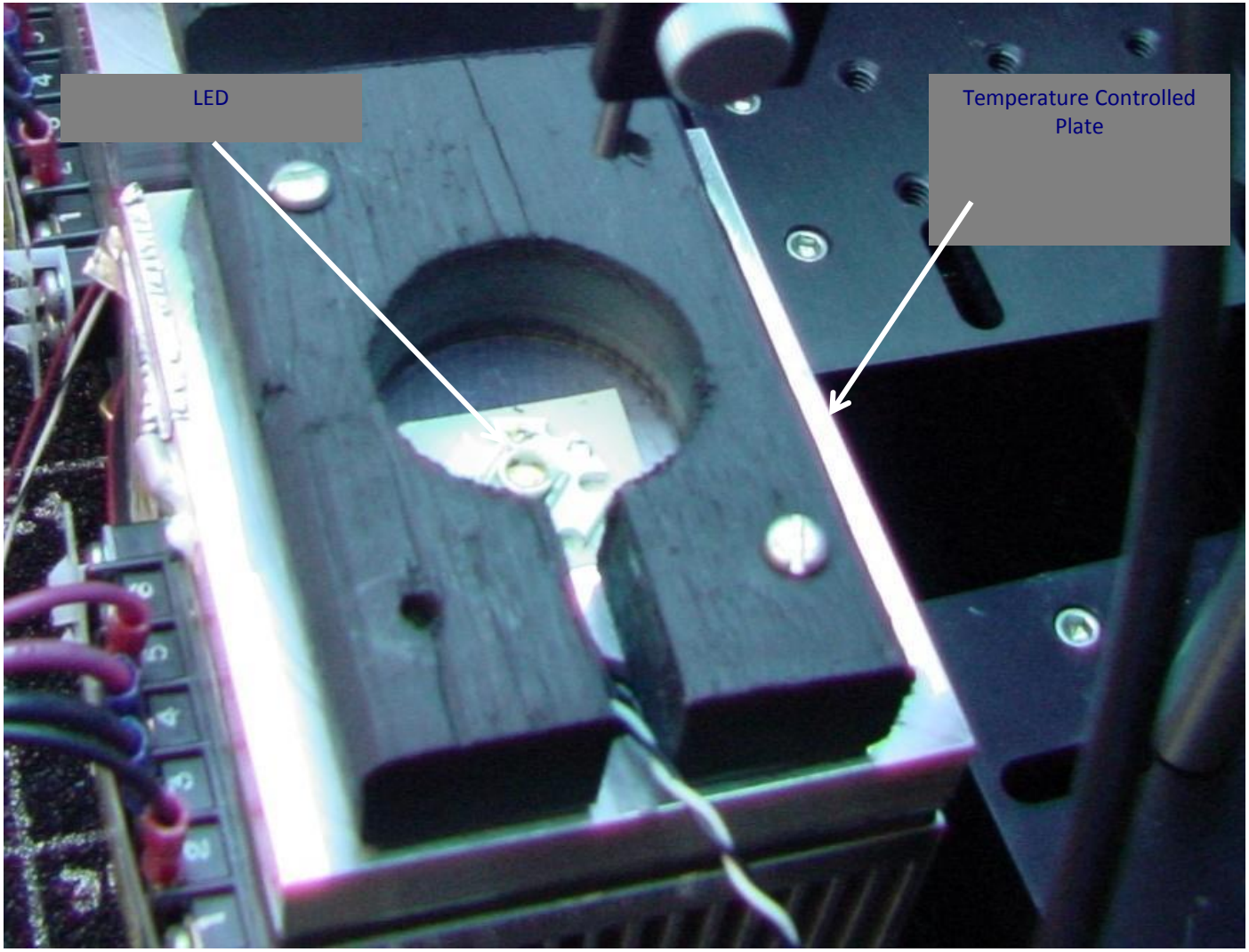
- Temperature stabilized white light LED produces a light source that is stable (<0.2% fluctuation over days) and allows for one reference to be made
- Spectra emission does not produce UV and overlaps well with Crystal Violet absorption



# Experimental Setup

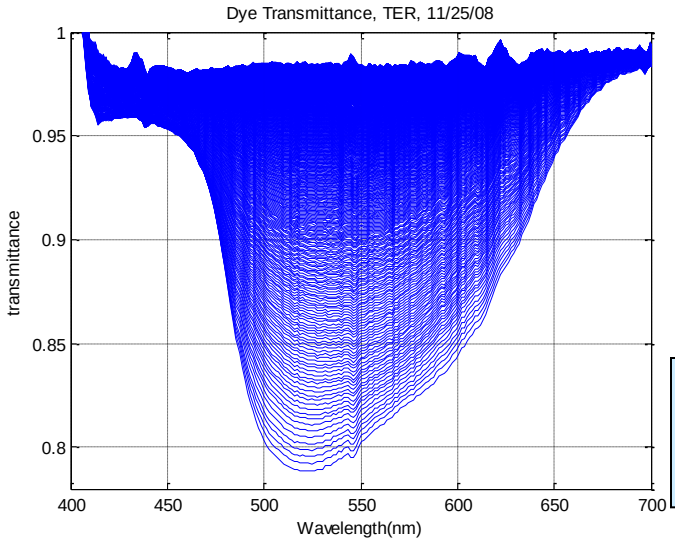


# Experimental Setup-Close-up



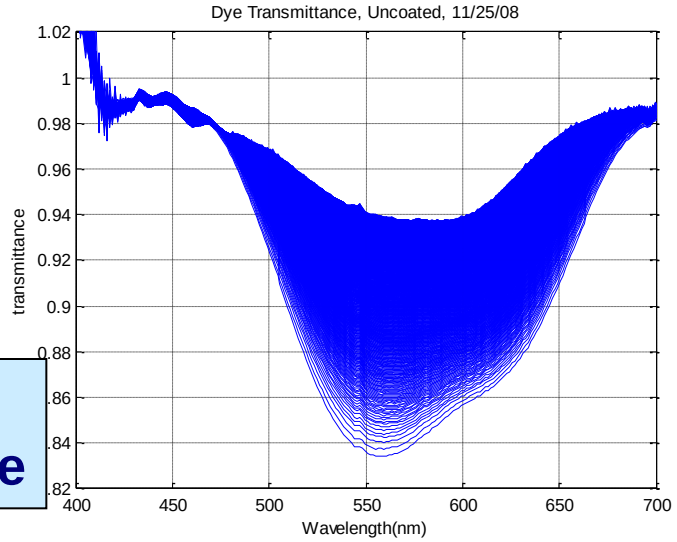
# Transmission Spectra Time Series

**Nanocepts, Inc. coating shows largest increase in transmission (4 hours)**

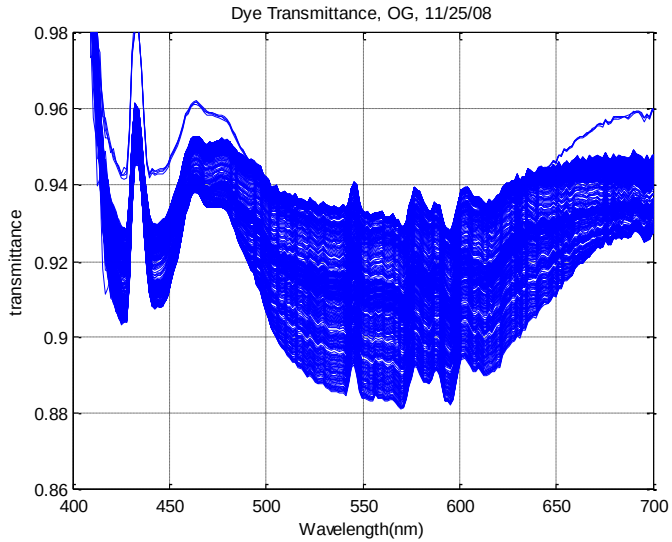



Nanocepts, Inc. coated slide

**Transmission increasing with time**




Uncoated slide

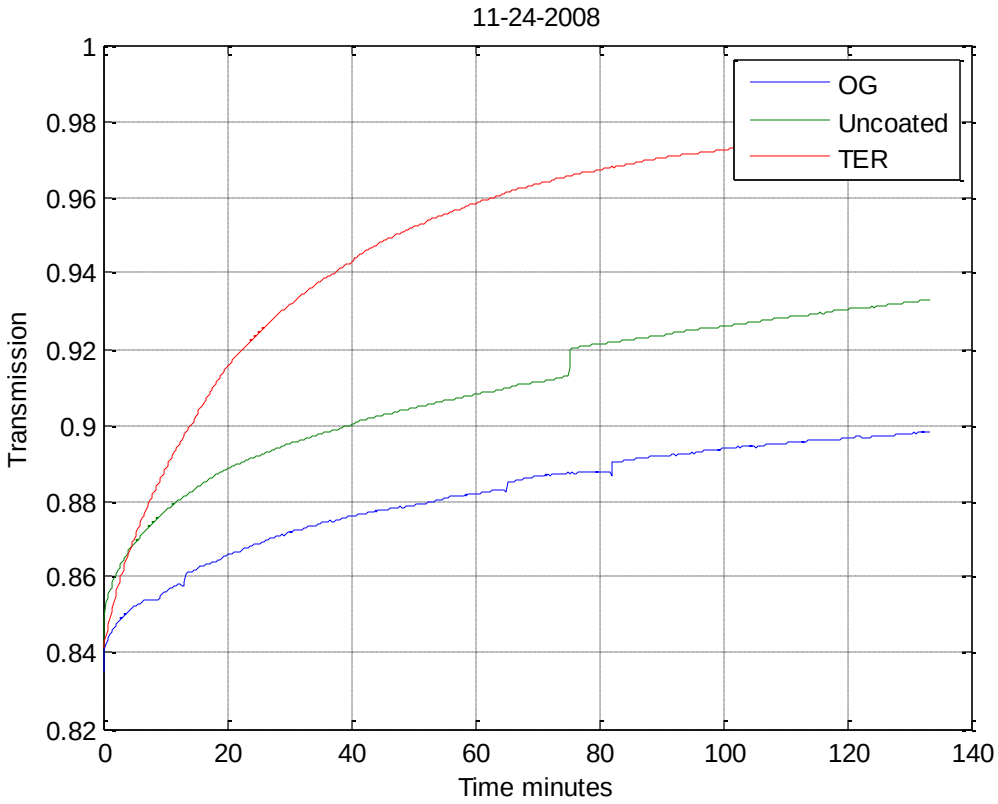



PURETi coated slide

# Peak Absorption Transmission Time Series

Stennis Space Center

- Irradiance 59 Watts/$m^2$
  - Similar to noon on a summer day
- Transmission at 550 nm plotted
- Three different slides
  - Nanocepts, Inc., TER-10 photocatalytic coating
  - PURETi, OG photocatalytic coating
  - Uncoated slide



# Peak Absorption Transmission Time Series

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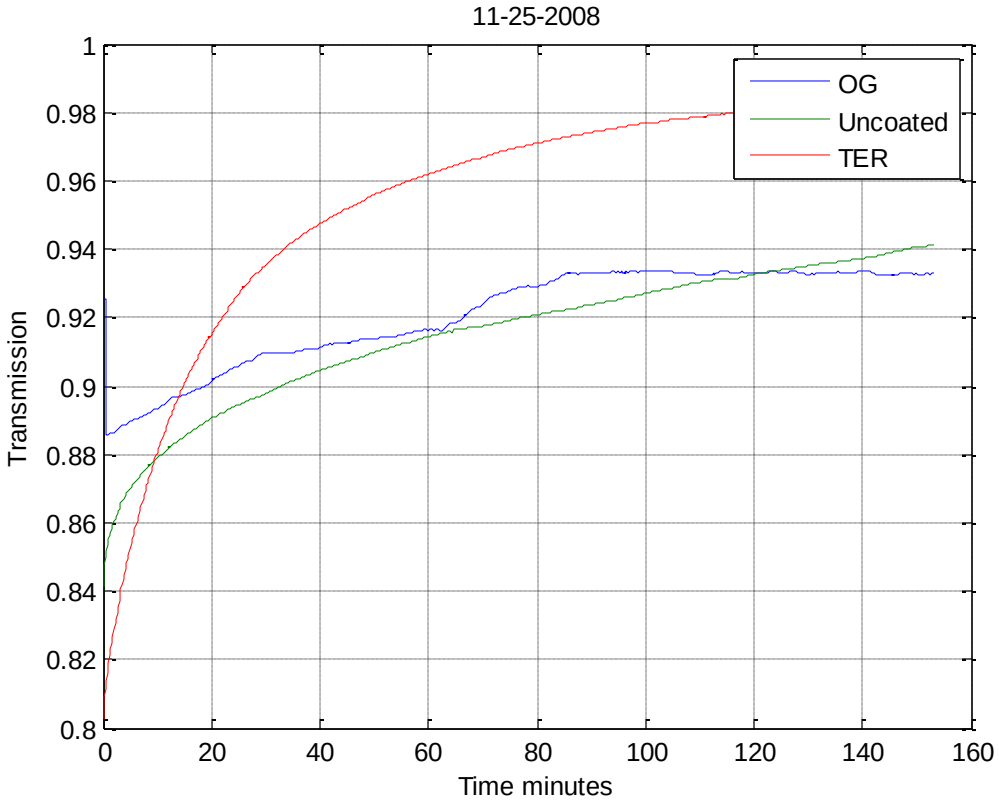


# Summary

- Simple method for evaluating photocatalytic reaction rate
- Nanocepts, Inc. coating clearly demonstrating photocatalytic activity
  - Small residual pure UV breakdown
  - Results replicated- consistent behavior observed
- Next steps
  - Additional materials to be evaluated
  - Compare results with chemical and biological analogs (in progress)
  - Additional UV levels being evaluated

# SSC CAN 2009 Dual Use

*CAN No. NNS09ZBA001C*

*SSC Cooperative Agreement Notice (CAN) 2009 for the Technology Development Program*

*Dual Use Technology Development*

## Investigating Photocatalytic Materials for Creating Building Sustainability and Self-Cleaning Surfaces

# Main Objectives/Task

- Two commercially available photocatalytic coatings were investigated
  - (1) to characterize their components and structure
  - (2) to assess their ability to maintain exterior surface cleanliness over time, and
  - (3) to study their photocatalytic function in a laboratory setting, using a non-photoreactive dye, so that preliminary scientific information can be documented on these commercially available materials.

# The following facilities/structures were used for this project:

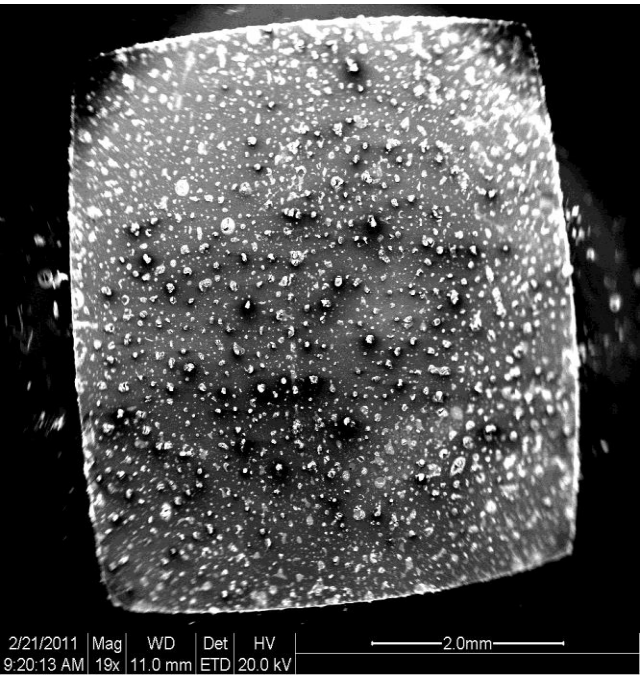
- The exterior surfaces of B-7001-not including the roof
- The two north faces of B-1200
- Booster rocket display-the the side of B-1200
- The Stennis Space Center greeting sight sign (a quarter mile south of the south gate)
- Electronic sign at the south guard gate
- All of the above listed facilities/structures were partially coated with commercially available photocatalytic coatings from the partners (Nanocepts, Inc. and PURETi).

# Methods and Results of Characterization Analysis

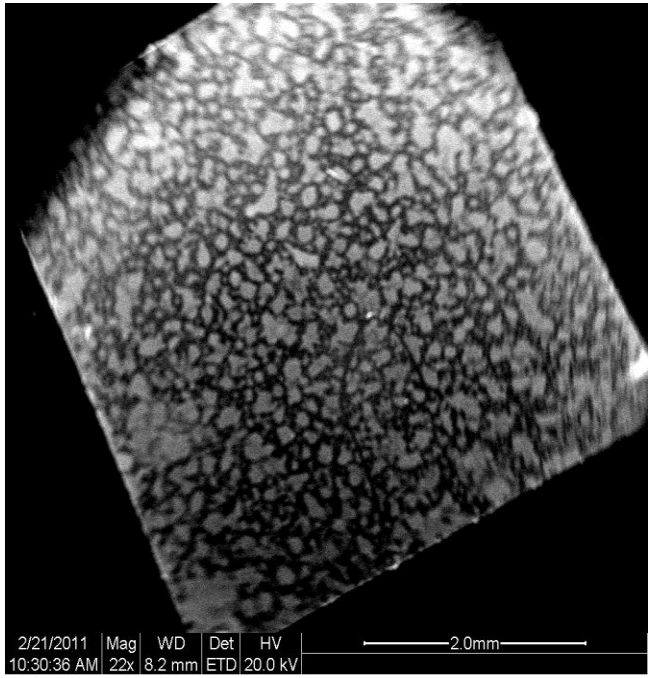
- **Physical testing:**
  - *Dynamic Light Scattering (DLS)*-provides information about particle size distribution in a suspension.
  - *Nanotrack* – obtains particle size based on light scattered from the particles in the suspension undergoing Browinian motion. This measurement will give particle size.
  - *Zetrack* – measures the interaction between field motion and Browinian motion of the suspended particles. This measurement will give particle size and zeta-potential. Zeta-potential is a measure of stability of the particles in solution.
- **Chemical composition analysis**
  - *Gas Chromatogrpahy/Mass Spectrometry (GC/MS)- This technique was used to detect any potential additives that were present in the commercially available aqueous topcoat solutions*
- **Analysis of surface features**
  - *Scanning Electron Microscopy (SEM)*- evaluate surface coverage and topology of the coatings once applied to a substrate.
  - *Transmission Electron Microscopy (TEM)*- to obtain a higher resolution image
  - *Energy-dispersive X-ray spectroscopy (EDAX*)- elemental analysis or chemical characterization of a sample
- **Thermal Analysis**
  - *Thermogravimetric Analysis (TGA)* - measures changes in sample mass with respect to temperature. Sharp decreases in weight percent correspond to evaporative loss of different chemical components of the chemical mixture.

# Low Mag SEM

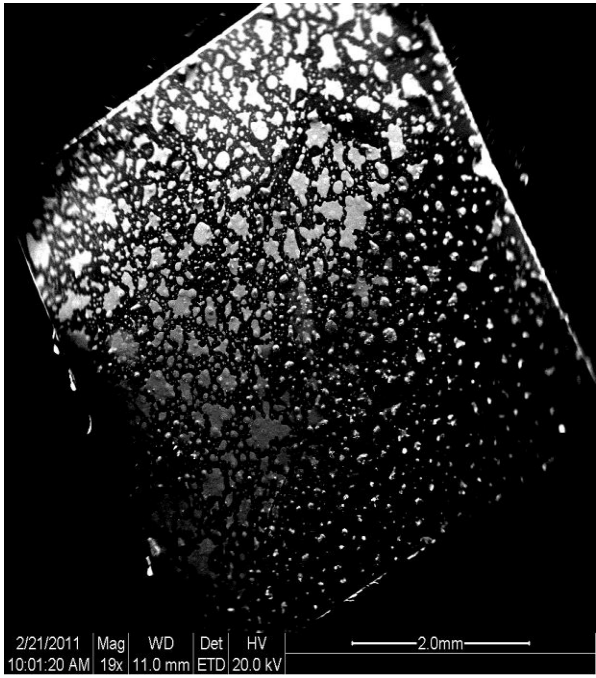
Clean 19x




Clear 22x



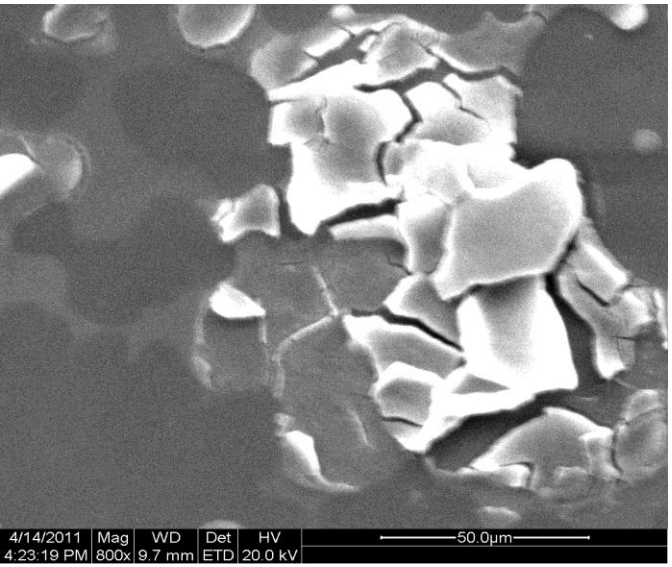

Skycoat K 19x



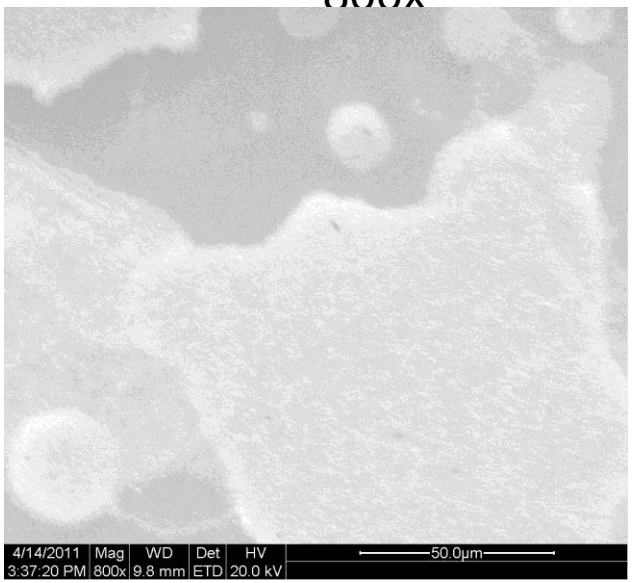

- Coating application on a silicon wafer at low magnification

# Higher SEM

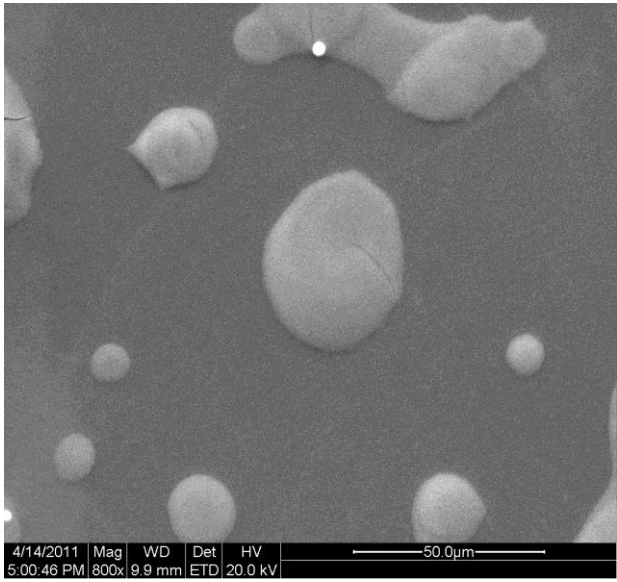
Clean 800x




Clear 800x



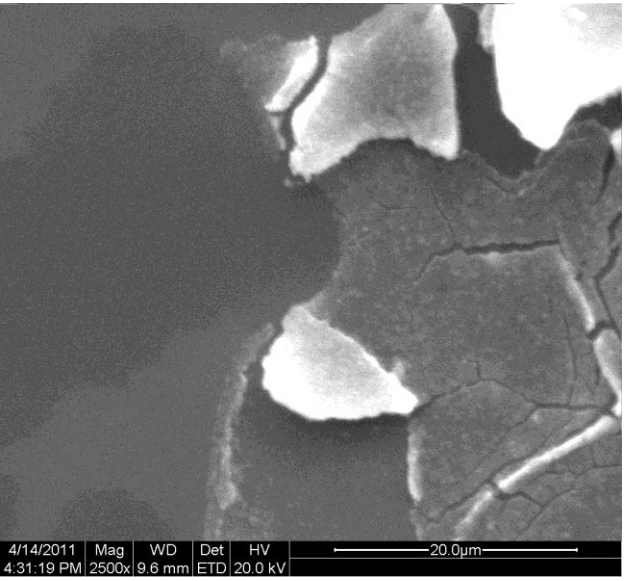

Skycoat K 800x



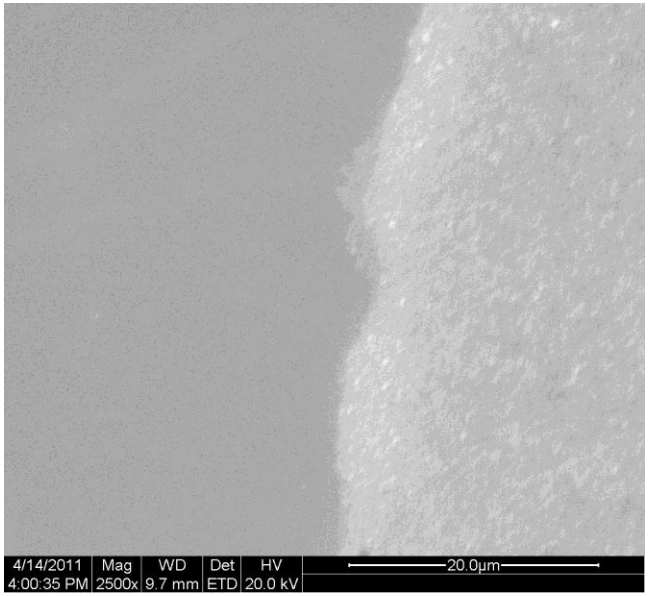

Higher magnification images of commercial coatings identifies differences among coating characteristics

# Higher SEM

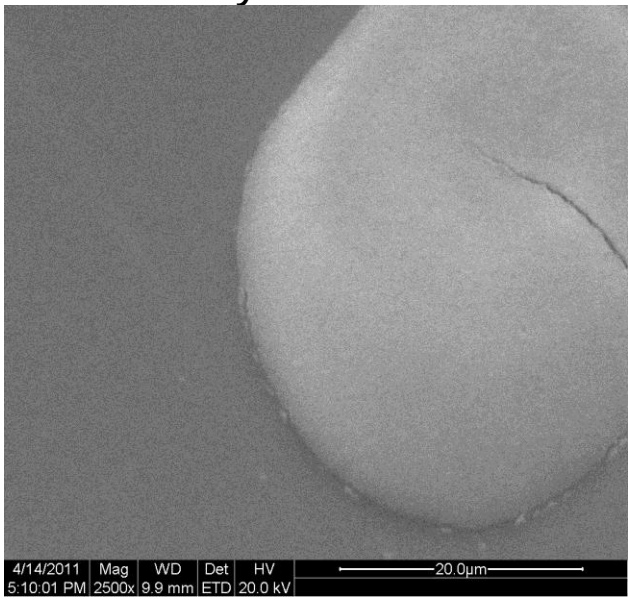
Clean 2500x




Clear 2500x




Skycoat K 2500x



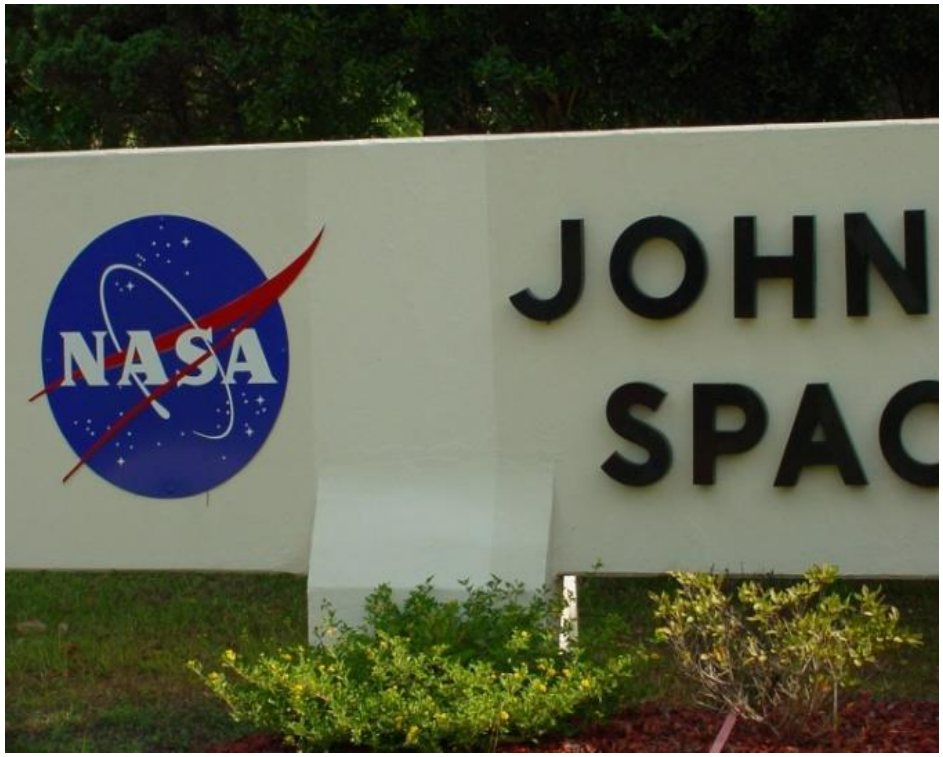

High magnification images at “edge” of coating and silicon wafer substrate

# Overall characterization results

- The analysis of the coatings that was supplied for this study, as compared to the MSDS (Material Safety Data Sheets) data sheets provided by PURETi and Nanocepts, Inc., was confirmed via GC/MS, TGA and TEM/EDAX. The data confirmed that these are aqueous base $TiO_2$ dispersions, in water, that have not been formulated with any additional additives (e.g., polymer stabilizers and surfactants). The DLS and SEM data demonstrated differences in relative particle sizes, the difference being that DLS is measurement is done in solution, while SEM is done with a coating.
- TGA measurements, thermal stability measurement, demonstrated that the dispersions consist of mostly water >98%. The residual 2% is due to the $TiO_2$ content in the dispersions, confirming what was provided to us by the companies that manufacture these dispersions.
- SEM and TEM was used to evaluate the coatings for surface coverage and topology, all inferences about cracking and adhesion were deduced from these images.

# Building Sustainability Results

NASA SSC Welcome Sign:




Photocatalytic coatings for creating green/sustainable buildings and structures

# Welcome Sign NASA SSC South Gate

10/19/2009

1/6/2010

# 6/30/2010

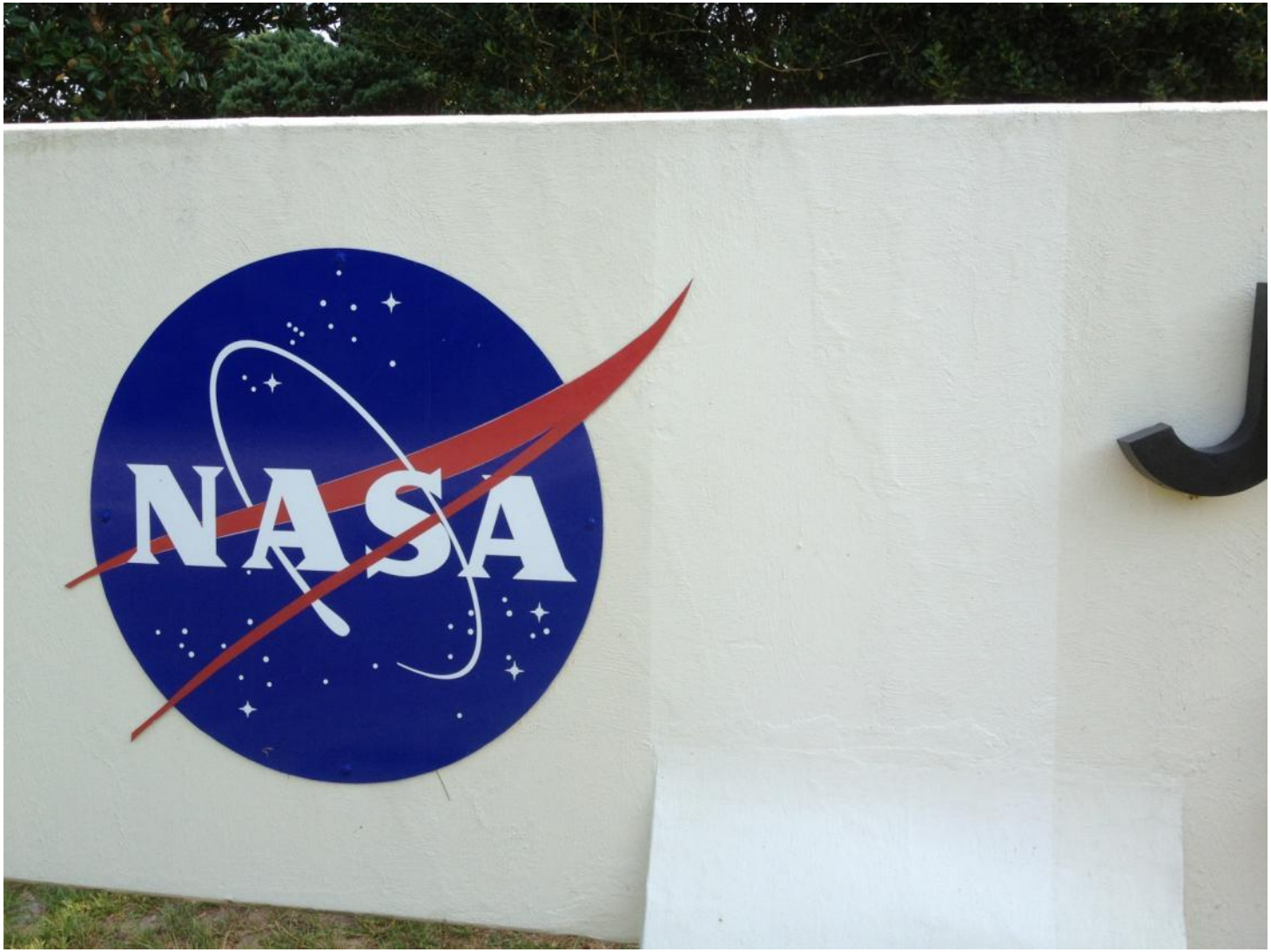
# 7/20/2010

# 5/10/2010

# 5/10/2010

# 6/16/2011

# 7/3/2012



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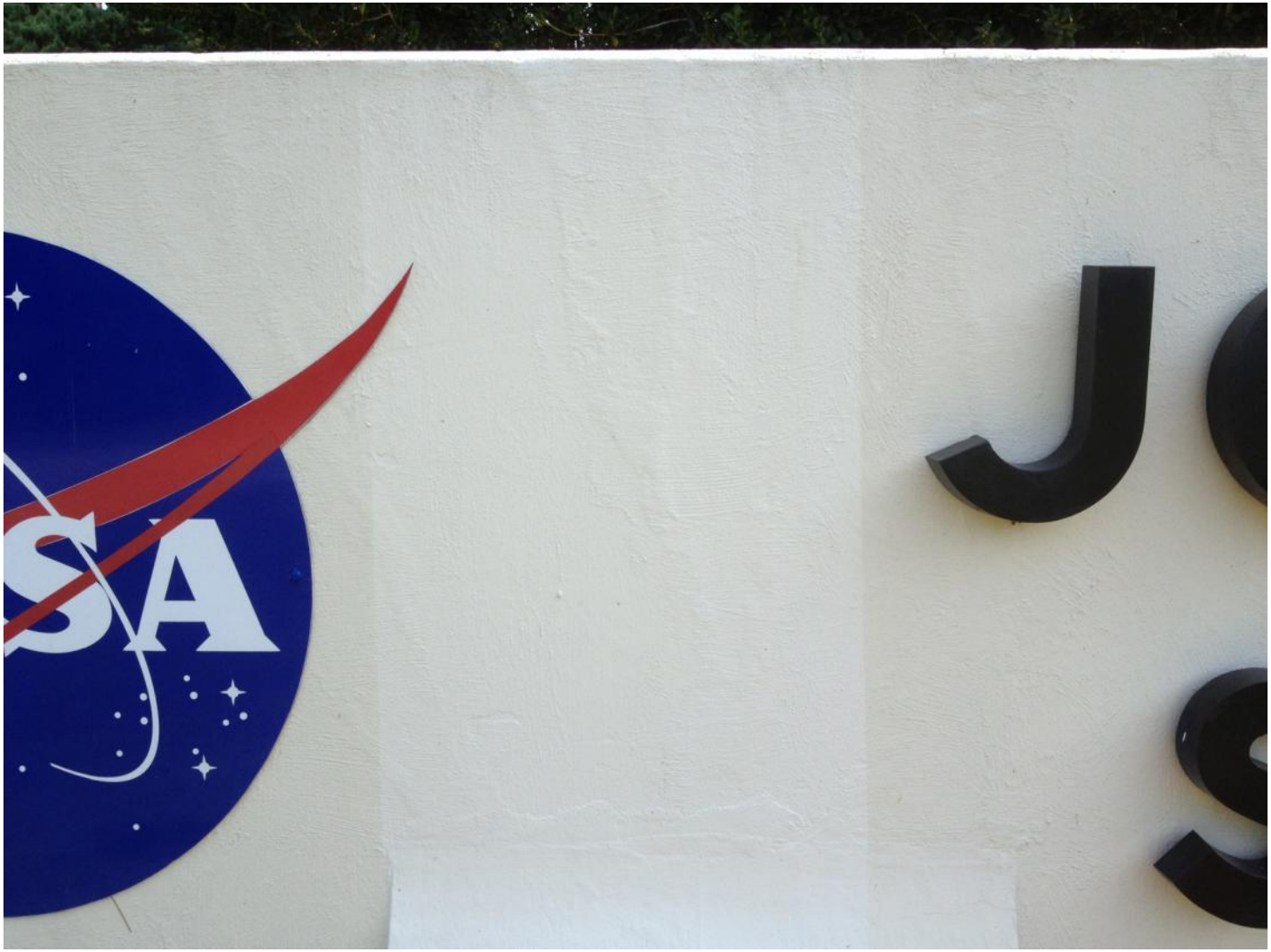
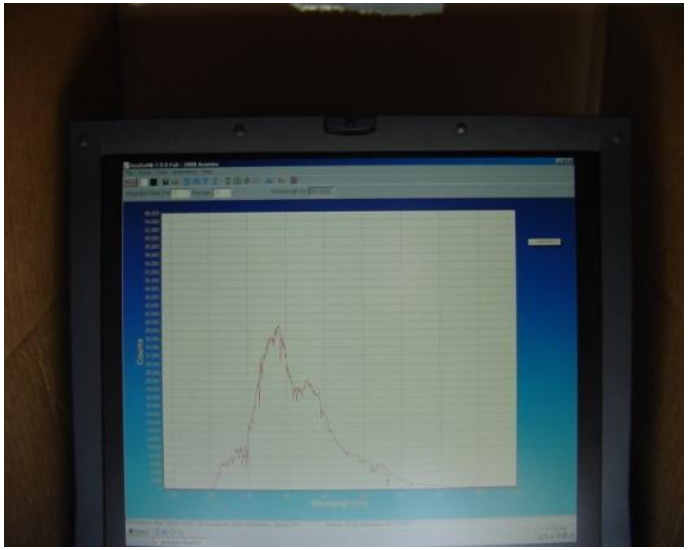


# In Situ laboratory results

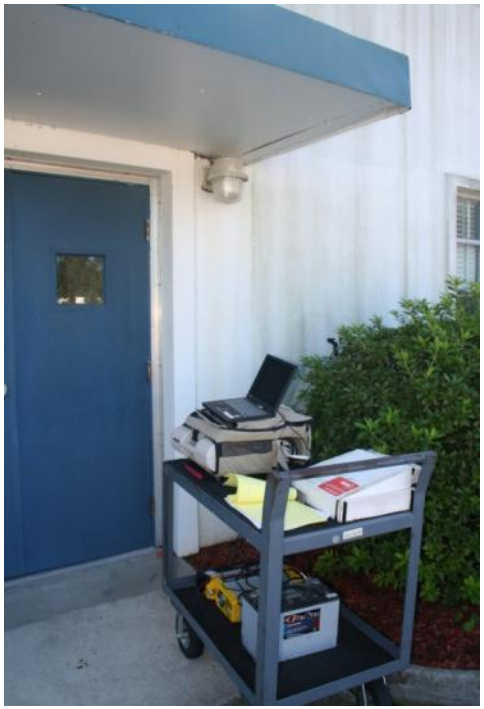
- Based upon the laboratory results from the dye degradation studies, $TiO_2$ coatings have demonstrated that they offer a potentially non-toxic mechanism to help protect the exterior surfaces of critical infrastructures from a natural or manmade disaster.
- $TiO_2$ coated slides successfully degraded crystal violet dye under UV light compared to dye samples on plain uncoated slides under the same conditions
- In order to provide more conclusive information about photocatalytic degradation capabilities, a critical component of future scientific designs should include the capability to quantify and characterize the amount of sample being applied to the photocatalytic coated slides, as well as the ability to measure the thickness of the photocatalytic coatings on the microscope slides themselves. At the time these studies were conducted, accessibility to of the type of equipment that would be necessary to obtain a value for the cross section of either the crystal violet dye coatings was not available. Had these values been attainable, this information and the absorption coefficient could have been used to estimate the thickness/density of the dye at early stages before the chemistry changes. Knowing the density and thickness of the dye would have enabled a better understanding of the reactions that are taking place, and it may ultimately be necessary to create an environmental chamber that could acquire different types of air sample measurements so that gas exchange between the products and reactants could also be better understood.

# Methods and Results of In Vivo Studies



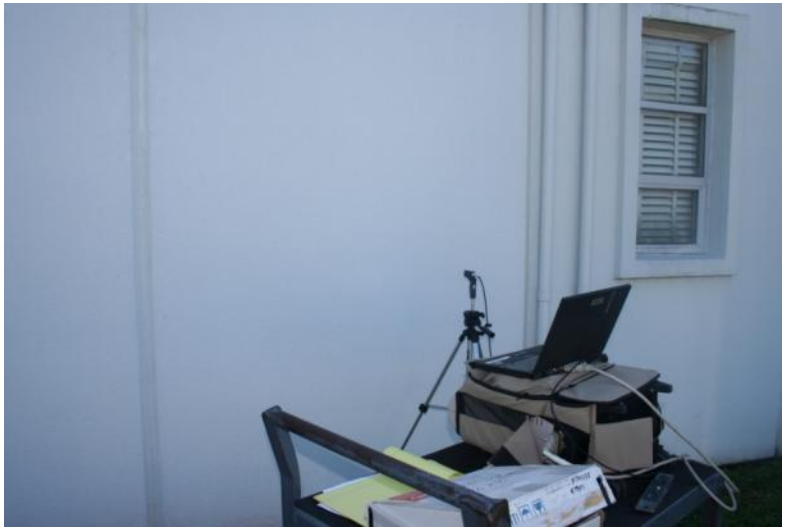
NIST calibrated spectroradiometers were used to perform outdoor surveys/assessments (in vivo analysis; Spectral reflection measurements from the buildings were captured using a spectroradiometer, and a use a NIST-calibrated ***Spectralon™ panel*** as a white reference source. Data was captured, saved and then processed; data was processed in EXCEL the reflected light from the building was captured through the spectroradiometer, and then it was divided by the reflected light from the Spectralon™ reference panel, and then the result is multiplied by the calibrated reflectance of the Spectralon™ panel.

# 11/19/2009



Spectral reflectance measurement set up outside building 1200

# 11/19/2009



Spectral reflectance measurement set up outside building 1200

# 5/28/2010

Spectral reflectance measurement set up outside building 7001

# 8/25/2010

Spectral reflectance measurement set up outside building 1200

# 1/3/2011

spectral reflectance measurements set up outside building 7001

# 7/3/2012: Building 1200

# 7/3/2012 Building 1200

# Spectral Reflectance Measurements

- Spectral measurements of the exterior surfaces of the following buildings were assessed for this project:
  - The exterior surfaces of B-7100-not including the roof
  - The two north faces of B-1200
- 
- The following surfaces were described and included for surface evaluation in the proposal,
  - Booster rocket display-the the side of B-1200
  - Electronic sign at the south gate
  - Welcome sign at south gate

# Spectral reflectance results

- To date, there is no documented scientific analysis of the spectral variability of reflectance measurements or documentation of optical properties of photocatalytic coatings.
- The shape and location of the absorption features demonstrated that the photocatalytically coated surfaces maintain a higher reflectance measurement, over time, as compared to the uncoated surfaces/
- There were some slight unexpected variability observed between the spectroradiometer measurements collected in May and June 2011, this variability could be ascribed to relative humidity changes, and/or operator inconsistencies. Ultimately, overall, the uncoated surfaces, demonstrate less reflection over time, when compared to the photocatalytically coated surfaces.
- These initial findings demonstrate that photocatalytic coatings could provide a viable means to increase building sustainability. Longer evaluation times, and increased surface area study would further validate these promising results.

# Conclusions

- Commercially available coatings appear to have good potential for improving building sustainability.
- These coatings can be sprayed to retrofit onto existing buildings and structures, and are currently being used and gaining increased popularity in other countries to keep buildings clean.
- Overall, the photocatalytic coating materials supplied by both partners, Nanocepts, Inc. and PURETi demonstrated properties that could aide in the creating sustainable buildings and structures.
- The project's year-long testing demonstrated from photographic documentary that visually the photocatalytically coated surfaces remain cleaner than the untreated surfaces, even when those surfaces were compromised (as in the case of the rocket booster).
- Additionally, from an analytical perspective, both commercial coatings also demonstrated that the surfaces that were photocatalytically coating maintained higher reflectance values, when compared to the uncoated surfaces.

# Conclusions

- *In situ* studies also confirmed that photocatalytic coatings are capable of degrading a non-photoreactive dye, demonstrating additional contaminant breakdown capability, which further increases sustainable potential of these materials.
- However, characterization analysis demonstrated that there are clearly differences between commercially available products.
- A primary concern when applying theses coatings is confluence of coverage. This is due to the fact that there is a direct relationship between photocatalytic activity and surface area exposure of photocatalytic molecules.  If there are issues with confluence of coverage, and expected surfaces are not optimally coated, or the coating is not smooth, this could affect overall photocatalytic function and efficacy. Therefore, more work is necessary to identify optical coatings because there slight differences in observed in surface features demonstrated via SEM and TEM/EDAX imagery.

# Conclusions

- Additional investigations should be conducted that characterizes photocatalytic coatings from multiple vendors to establish a database of likely candidates for future sustainability use.
- In conclusion, the experiments described above provide evidence that TiO2 photocatalytic coatings have the potential for an application as tool for protecting buildings and structures from natural and manmade disasters, however, further research must be done to provide a better understanding of this photocatalysts characteristics and abilities.

# NASA SSC's Center Director's Discretionary Funds (CDDF) FY10

"*Time Series Assessment of Photocatalytic Surface Coatings for Creating Self-Cleaning Sustainable Buildings and Structures*"

# Technical Approach

## *Technical objective.*

- Photocatalytic coating and service required for application were provided by the following companies:
  - Nanocepts, Inc., Coldstream Center, 1500 Bull Lea Road, Suite 201, Lexington, KY 40511, 859-396-4339 http://www.nanocepts.com/about.htm

and

  - PURETi, 2849 Product Drive, Rochester Hills, MI 48309, 248-299-2607 http://www.pureti.com/about.html

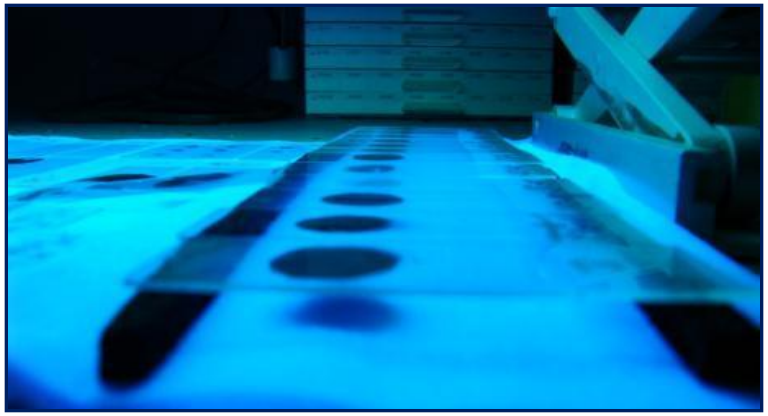
Photocatalytic coatings from both these companies can be readily applied to existing surfaces, have previously demonstrated photocatalytic self-cleaning properties, and are currently being retrofit onto existing structures in the United States.

The following facility/structure was used in this study:

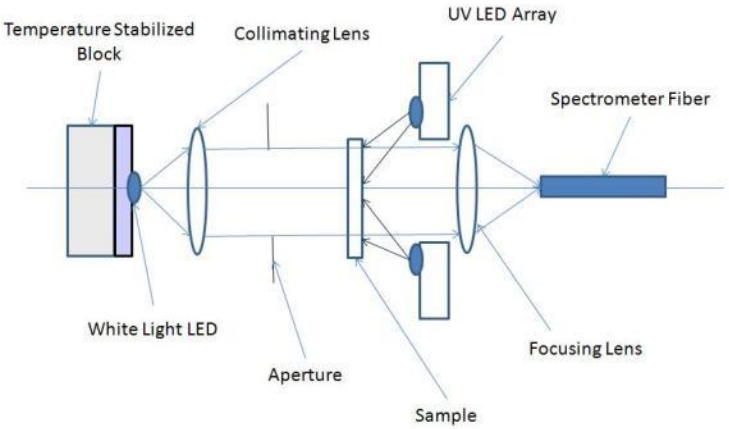
- The new Cryogenic Facility (building 3418), on Propellant Blvd.

# Laboratory Assessment

soot on $TiO_2$ coated glass surfaces and monitoring their decomposition



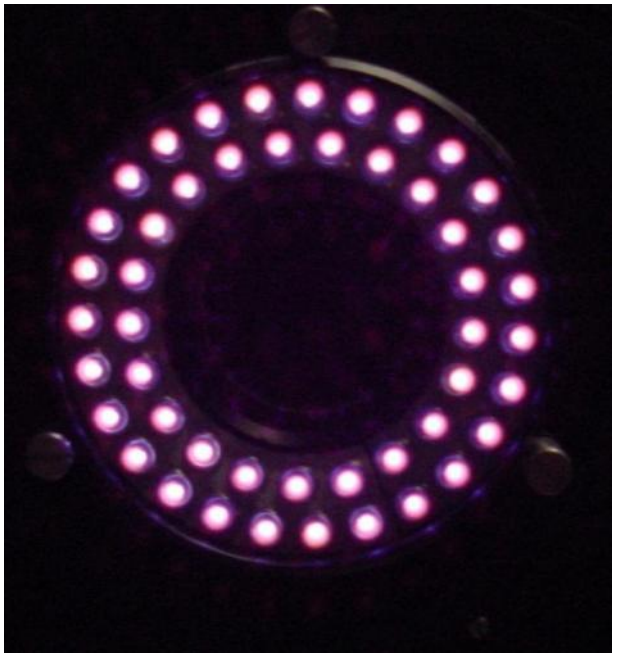
Soot deposited on microscope slides and exposed to UV lamp to induce photocatalytic activity.

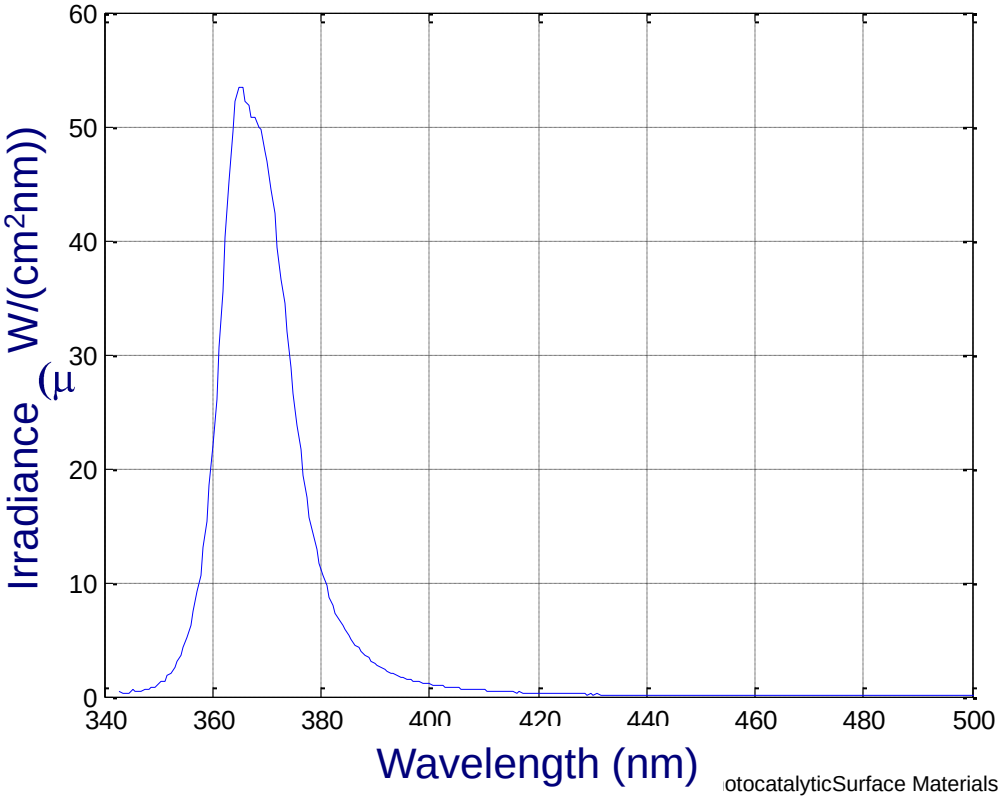



A schematic of the set-up used to take transition measurements

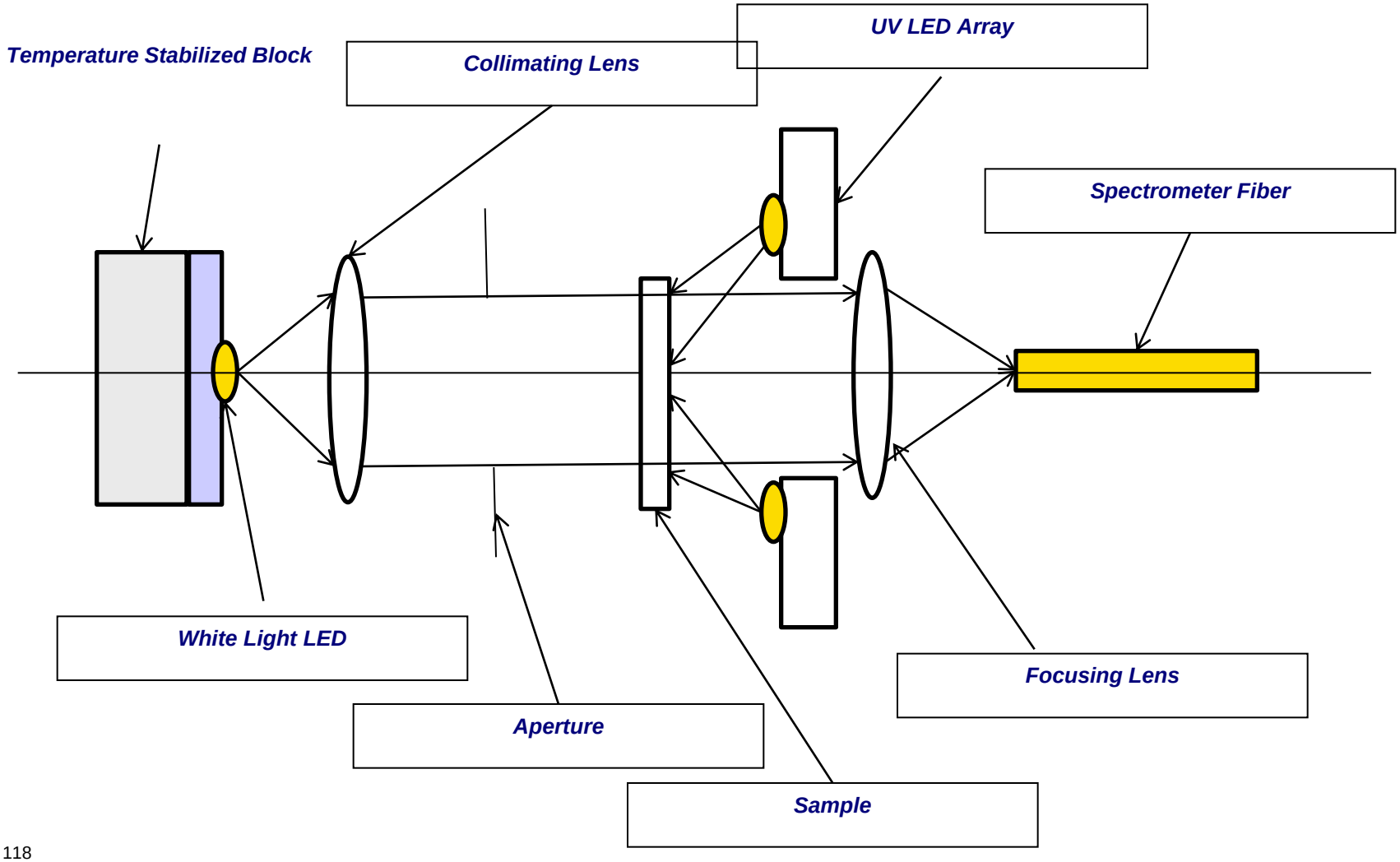
# New UV Illumination Approach

- Replace Black Lamp with UV LED array
- DC powered  continuous light source
- Intensity can be easily adjusted

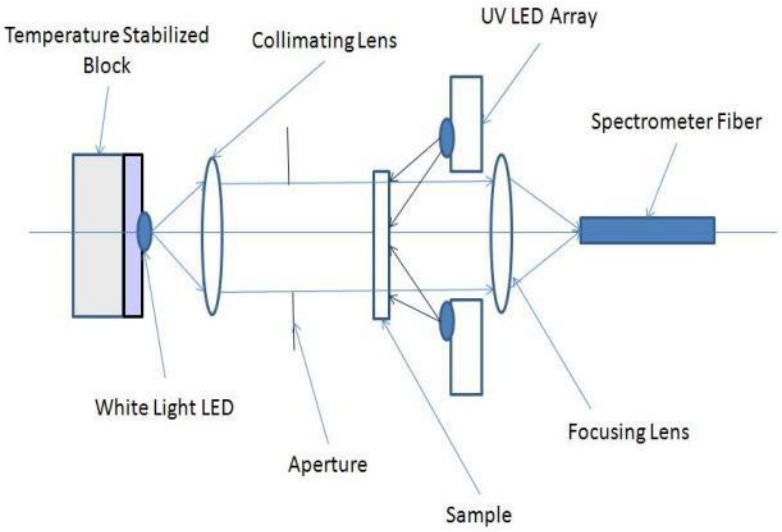


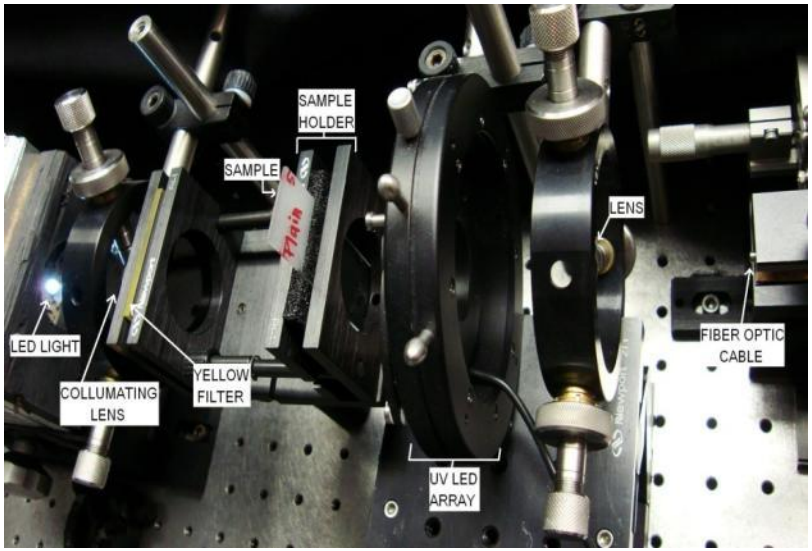


# Schematic of New LED Approach

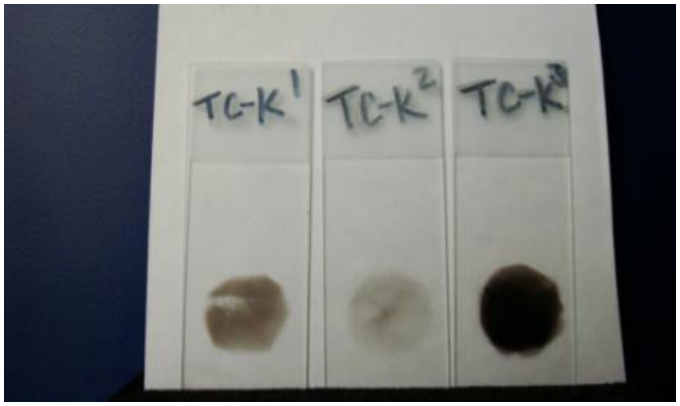


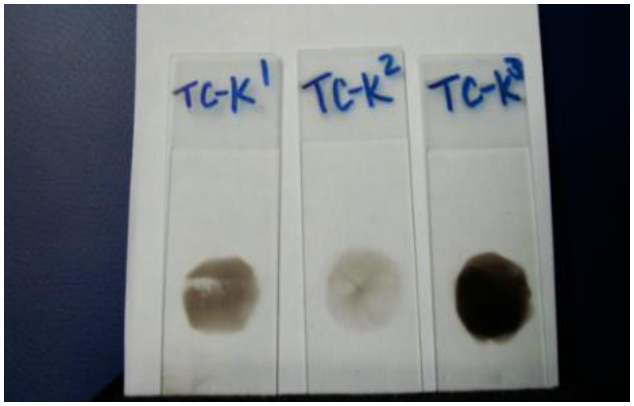
# A schematic of the set-up used to take transmission measurements.



# Photocatalytic decomposition of soot




The microscope slides on the left depict three different thicknesses of soot, TC-$K^1$ (medium thickness), TC-$K^2$ (light coating) TC-$K^3$ (heavy coating) applied to a Nanocepts, Inc. photocatalytically coated slides(TC-K coating); on the left, the slides are show after 4 weeks UV light exposure; on the right, the slides are shown after 6 of UV light exposure. The TC-$K^2$ slide with the lightest soot deposit demonstrated the greatest amount of decomposition. These results were validated with light transmission measurements.

# Discussion and Conclusion

- $TiO_2$ coated surfaces demonstrated both visually through photographic representation, and quantitatively, through reflectance measurements that they improved upon the current state of cleanliness upon the surfaces that they were applied to
- $TiO_2$ has the potential to both maintain and increase building's sustainability and the overall appearance of cleanliness
- $TiO_2$ coated slides degraded soot under UV light compared to soot samples on plain uncoated slides under the same conditions
  - Degradation of soot by photocatalysis was far more apparent than degradation of soot by UV light alone
  - This demonstration provides the foundation for a laboratory model that could be used to simulate real world applications for photocatalytic materials
- Additional research is required to better understand the full potential of $TiO_2$

# Southeast Region Research Initiative (SERRI)

Department of Energy's Oak Ridge National Laboratory for the U.S. Department of Homeland Security funded project FY10-FY11

*"Assessing the Potential of Photocatalytic Building Materials for Protecting Infrastructure and Developing Resiliency to Natural and Manmade Disasters"*

# Project Overview

- Limits of photocatalytic material use to homeland security
- lack of standardized testing techniques and limited understanding of material performance under real world conditions;
- lack of predictive tools to estimate their performance;
- lack of predictive tools to estimate costs of utilizing photocatalytic materials
- safety concerns associated with nanoparticles

# Project Tasks

- Task 1: Material selection and initiation of database development
- Task 2: Photocatalytic material characterization
- Task 3: Illumination surveys and PcAR predictions
- Task 4: Laboratory illumination instrumentation development
- Task 5: Performance Database: Surface decomposition rates for chemical analogues
- Task 6: Performance Database: Surfaces decomposition rates for biological analogues
- Task 7: Performance Database: Super-hydrophilic properties of photocatalytic materials

# Infinity Science Center at NASA

*Stennis Space Center*

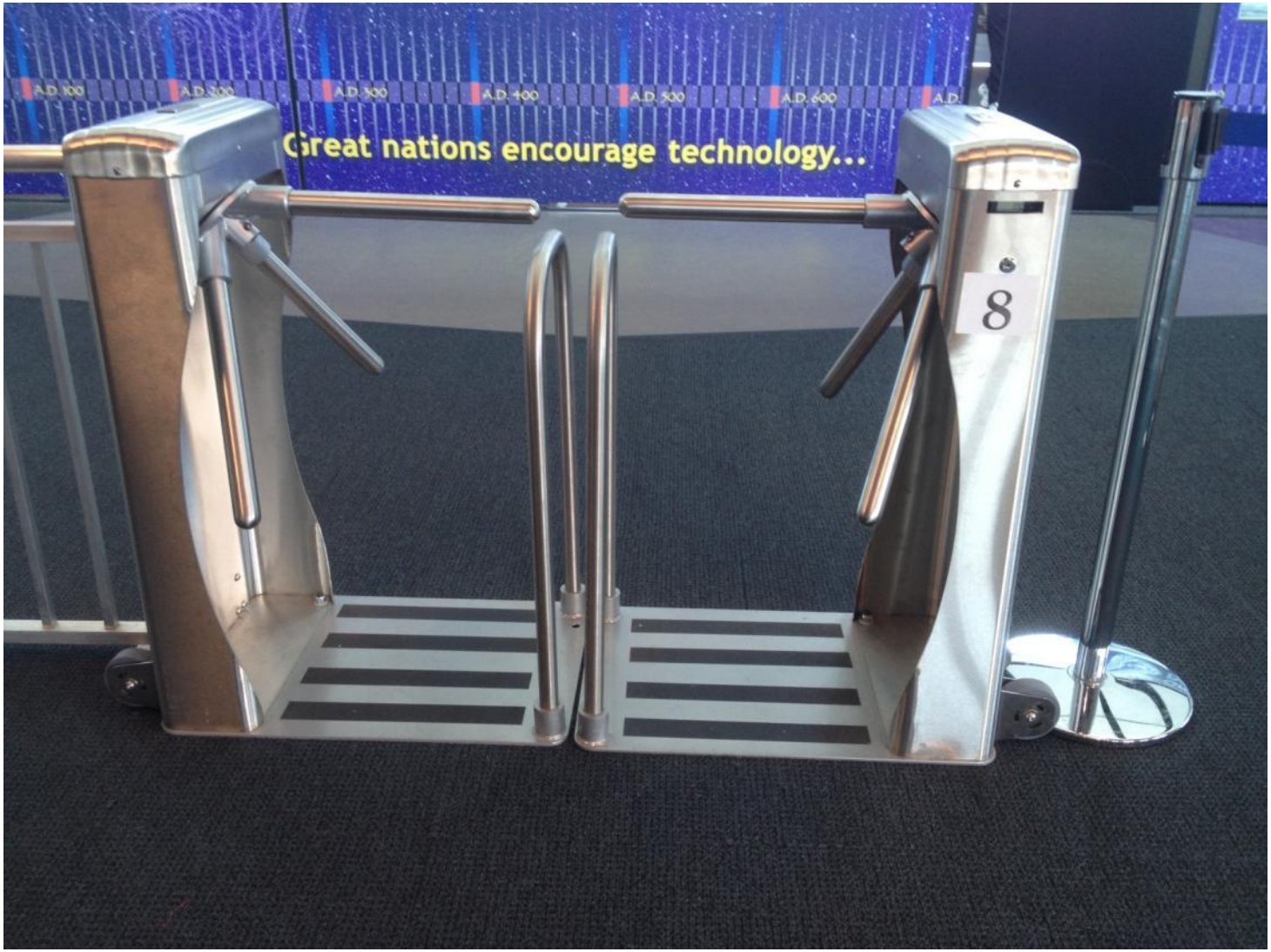
**State of the art science center and visitor attraction in Hancock County, MS**

# Proposed Studies at Infinity

- Self-Cleaning Validation Experiment
  - Various surfaces will be photocatalytically coated at the Infinity Science Center i.e. turnstiles, doors, and/or frequently touched glass surfaces, and then quantitatively examined for their self-cleaning capability
- Infinity Science Center Indoor Air Quality Exhibit
  - An air purifying exhibit will be created for display
  - The exhibit will demonstrate the dual use of photocatalytic material technology: $TiO_2$ + new UV LED light source
    - Ultra bright GaN LEDs-commercially available within the past year;
    - Last 10s of 1000s of hours;
    - Resistant to mechanical stress;
    - Critically important for future space missions and terrestrial applications

# West Entrance Turnstile

# East Entrance Turnstile



# Hand-on "Touch Surface" Experiment

Source: http://www.visitinfinity.com/exhibits/great-nations/

# Glass Elevator

# Entrance: Glass Revolving Door

# Demonstrative Collaboration

- Global Applied Technology, Design and Engineering, Department, Walt Disney World Co. (TWDC)
- Infinity Science Center
- NASA
- NASA Information Technology Services Contractor
- PURETi
- Nanocepts, Inc.
- Innovative Imaging and Research

# Leveraging Capabilities and Desired Outcomes

By leveraging Walt Disney World and NASA's similar notions about developing and implementing creative ideas for building sustainability, the objective of this project is to help lead the world into a "greener and healthier tomorrow.

NASA and Disney will work together to provide the public sector with science and real-world results (of these photocatalytic coatings), track progress towards the essential goal of establishing real-world sustainability product, and share their findings to support the validity of this innovative technology.

# NASA and TWDC could work together

to compare scientific investigations of commercially available photocatalytic coatings

- (1) for characterization of their components and structure
- (2) for assessment of their ability to maintain exterior surface cleanliness over time, and
- (3) for understanding their performance in a laboratory setting, and
- (4) provide demonstration of this information through the INFINITY science center so that preliminary scientific information provided on these commercially available materials can be made available to the public in a real-world setting.

In this way, NASA and TWDC's expertise, combining creativity, technology, innovation, will be incorporated to deliver this critical element.

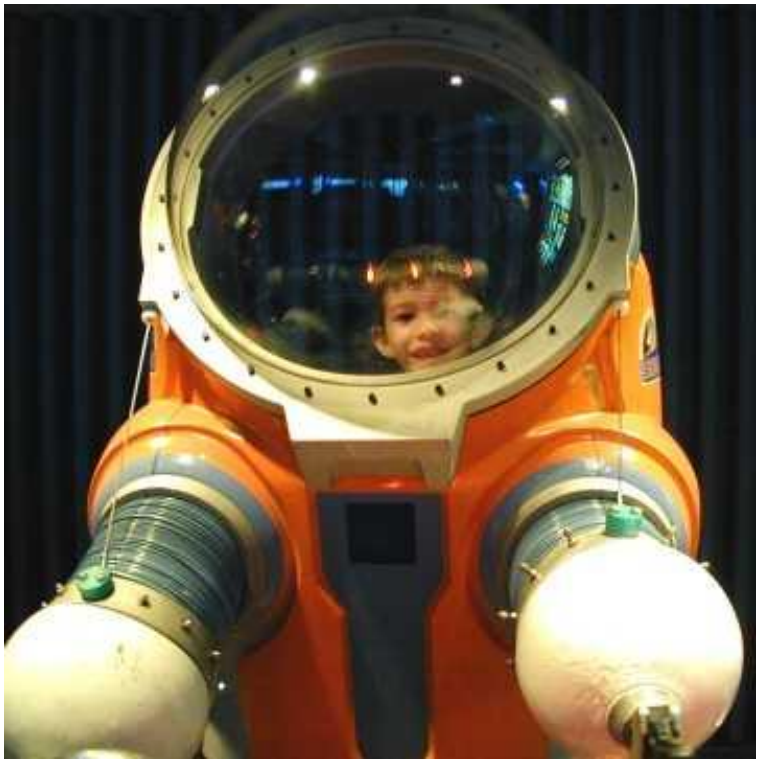
# Possible Collaborative Efforts

Source: http://en.wikipedia.org/wiki/File:Disney_bus_in_Walt_Disney_World,_Florida.jpg

Soucre: http://www.visitinfinity.com/visitor-info/bus-tour/

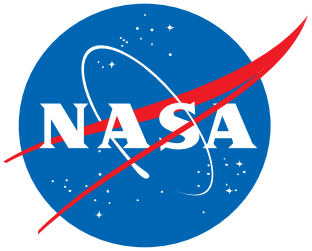
# NASA and TWDC





Liviing Seas Diver Suit at **Epcot**
Source: http://vinylmationkingdom.com/wp-content/uploads/2012/01/livingseasdiver.jpg

Space Suit at **INFINITY Science Cen**ter at NASA's Stennis Space Center near the Interstate 10 Mississippi Welcome Center Wednesday April 11, 2012.
Source: http://www.nola.com/travel/index.ssf/2012/06/mississippi_gulf_coast_vacatio.html



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Research into photocatalytic technology has been progressing for over three decades in the early 1990s Japanese and European companies initiate research into photocatalytic technology. In the 1996 specific focus on the technology with the first large-scale application: the construction of a church in Rome (Jubilee Church). And in 2000 Europe and Japan research into the benefits of photocatalytic technology. Currently, photocatalytic technology continues to improve, and with time development is becoming more efficient and effective.
What is Photocatalysis? Photo: phenomenon induced by the light, having specifically a wavelength around 320-400 nm (artificial or natural sunlight). Catalyst: a material that induces a reaction but is not consumed or transformed by it. The catalyst remains constantly available. In this case, the catalyst is made with nano-particles of titanium oxide (TiO2).

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